Rehabilitation Engineering Center
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The focus of research activities in the Case Western Reserve University Rehabilitation Engineering Center is directed toward restoration of upper-extremity function. Projects involve restoration of motor function through functional electrical stimulation and tendon transfer, electrotactile stimulation for sensory augmentation, development of command control signal acquisition, and evaluation of abnormal motor control. Mobility studies include development of control sources for powered wheelchairs, and evaluation of the therapeutic effects of functional electrical stimulation in gait.

Restoration of Upper-Limb Function through F.E.S.

Principal investigators:
P. Hunter Peckham, Ph. D.
Alvin A. Freehafer, M.D.
Michael W. Keith, M.D.
E.B. Marsolais, Ph. D., M.D.

These studies are the core area of research in the center. The purpose of the project is to develop and evaluate systems employing functional electrical stimulation to provide control of hand movement. These studies are being performed in conjunction with the VA Rehabilitative Engineering R & D program, and the current status is detailed elsewhere in this issue of the Bulletin.

Restoration of Upper-Limb Function through Tendon Transfer

Principal investigators:
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The purpose of this study is to investigate techniques for improving upper-extremity function in spinal-cord-injury patients through the use of tendon transfers. We are presently monitoring function of the transferred muscle during surgery to establish proper functioning of the transferred muscle-tendon unit.

In the past period, nine additional quadriplegic subjects undergoing elective tendon transfer in the upper extremity have been evaluated. The results of these subjects are similar to those previously reported for both excursion and length-tension, and provide the surgeon with quantitative information upon which the length of the transfer can be determined.

Studies are also underway to monitor the activity patterns of muscles following transfer in order to assess the patient's ability to gain selective voluntary control of the transferred muscle-tendon unit. In the next period, we will pursue these studies and incorporate additional new candidates for intraoperative measurement of muscle properties.

Sensory Substitution Using Electrocutaneous Stimulation

Principal investigators:
Ronald Riso, Ph. D.
Michael W. Keith, M.D.

The objective of this project is to develop feedback devices to provide patients having asensory or prosthetic hands with an awareness of the extent of opening of their hand or prosthesis and the amount of grasp force being applied to an object.

A technique is being developed which involves stimulating the skin subdermally by using percutaneous electrodes made of fine coiled stainless steel wire. Initial experiences with two subjects have been encouraging. Stimulation with single pulses or bursts of pulses (pulse width 10–100 μsec; freq. 2–100 Hz) has consistently elicited clear, distinctive sensations, which the subjects report are more comfortable and more consistent than those felt when surface electrodes are employed. Participation of one subject for nearly 4 months has demonstrated that the electrodes remain viable in their ability to elicit skin sensation, and that the level of current required for this remains small.

Immediate plans for the future include an optimization of stimulus parameters for a frequency modulation code which will provide for grasp force feedback.

Command Controller Development and Evaluation

Principal investigators:
Dennis Roscoe, Ph. D.
Michael W. Keith, M.D.

A multichannel command system, currently under development, would allow quadriplegic and upper-extremity amputee subjects to proportionally control a functional neuromuscular stimulation system and a powered prosthesis respectively. Myoelectric

signals will be recorded from the subject's intact musculature with an intramuscular array of bipolar electrodes linked to a multichannel telemetry device. Telemetry data will be received by a microprocessor-based myoprocessor and converted into control signals.

To date, an electrode array design (1.5-mm-long stainless steel pins molded into a Silastic backing) has been implanted into the lateral triceps of a cat with lead wires exiting the animal via a transcutaneous connector mounted over the scapula. Stable myoelectric signals have been recorded from this preparation for 6 weeks with impedance values in the 2 to 3 Kohm (1000 Hz) range. Power spectra and correlation analysis between various electrode pairs within the implanted array are presently in progress.

A telemeter design has been formulated and is presently being breadboarded. The prototype device consists of four channels of pulse-code-modulated data with a one kilohertz bandwidth per channel. The circuitry is being realized with CMOS devices, with plans for integrating most circuit functions into a single semi-custom CMOS chip. The telemeter will be RF powered (10 MHz) and will use a 60-MHz data link. A titanium package is being designed for its final implantable configuration.

A single-channel myoprocessor has been evaluated with the use of a laboratory digital computer. It incorporates three processing steps: (i) demodulation; (ii) a running average; and (iii) relinearization. Preliminary data has shown this single-channel myoprocessor to produce a greater than two-fold improvement in the signal-to-noise ratio (SNR) of the control signal over that of conventional processing (rectification and low pass filtering). Development of a two-channel myoprocessor will be initiated within the next several months. This processing scheme expands the single channel technique by combining two myoelectric sources from the same muscle for further SNR improvement of the final control signal. An additional processing step involving spatial prewhitening is necessary to equalize the contribution of each myoelectric imput channel. Overall, SNR improvement by the two-channel myoprocessor is projected to approach five-fold.

Evaluation of Abnormal Motor Control

Principal investigators:
Patrick E. Crago, Ph. D.
George H. Thompson, M.D.

The objective of these studies is to measure quantitatively the mechanical and neural components of the response to muscle stretch and shortening in patients with spasticity, and to compare these with the responses in normal subjects. In the previous report, we described our initial results in normal subjects on the dependence of the response (angle and EMG) changes elicited by a step torque change measured at the thumb interphalangeal joint on the torque established by the subject prior to the disturbance, and on the magnitude of the step disturbance. Stiffness, which is the ratio of change in torque to change in angle, decreased with increasing initial torque, suggesting that stiffness is not well regulated by stretch reflexes.

The data have been analyzed further during this report period, and the experimental protocols have been redesigned to give a more complete analysis of the responses to external disturbances. One of the principal changes that is being made is to change from regulated torque disturbances to regulated angle disturbances. Regulated angle disturbances are preferable for several reasons. First, when studying the dependence of stiffness on initial torque or initial angle, any nonlinearities would not be compounded by the nonlinear incremental torque-angle relationship. Also, passive viscoelastic properties and nonreflex muscle mechanical properties are more easily studied with regulated angle disturbances. We are presently making the hardware changes that are necessary to switch to regulated angle disturbances. The changes that are required are (i) construction of a waveform generator that can be programmed and controlled by the laboratory computer, (ii) design of a controller to regulate the angle of the torquemotor, and (iii) alterations of the data collection software to provide control of the waveform generator. The waveform generator has been completed and the controller is about 25 percent complete. About 50 percent of the software alterations are complete.

During the next report period, the modifications to the protocols will be completed and tests will be continued to establish a database in normal subjects. This database will include contributions of passive viscoelastic properties, active muscle mechanical properties, and muscle reflexes to the total responses measured at the joint.

Control of Abnormal Muscle Contractions

Principal investigators:
Ronald R. Riso, Ph. D.
John T. Makley, M.D.

The objective of this project is to investigate the efficacy of using functional electrical stimulation (FES) of muscles to produce improvement in the walking function of cerebral palsy children. We apply 20 minutes of daily FES to the peroneal nerve in children who walk with a drop-foot, or who walk with an equinus foot posture due to spasticity of their ankle extensor muscles. Through collaboration with the Cleveland VA Medical Center Motion Study Laboratory, clinical (instrumented) gait analysis is being used to detect and to document any changes in the gait that may be caused by the FES.

Thus far, two patients out of eight who have been treated for several months to more than 1 year have shown a significant improvement in foot posture during walking as a consequence of having received daily FES treatments. Two additional subjects were admitted into the program in December 1981.

Following completion of at least 4 months use of FES treatments by these new subjects, a formal publication detailing our findings for all of the patients will be prepared for publication.

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Interaction of Knee Ligaments with the Geometry of Total Knee Ligaments

Investigators:
William D. Lew, M.S., Jack L. Lewis, Ph. D., Michael J. Askew, Ph. D., and John Steege, B.S.

Many retrieval programs or clinical series of total knee replacements (TKR) report that loosening of the tibial component is a major cause, if not the major cause, of TKR failure. The objective of this work is to identify possible ligamentous constraints (abnormally high ligament forces) which occur as a result of improper interaction of TKR geometries with knee ligament mechanics. Such constraints may increase prosthesis/bone interface stresses, thereby contributing to the loosening process and ultimate failure. Once ligamentous constraints are identified, design changes or proper choice among existing TKR designs can be made, thereby reducing the failure rate and enhancing the successful use of total joint replacements in eliminating disability due to arthritis.

Preliminary work involved the development of experimental and analytical tools for evaluating knee ligament mechanics as a function of TKR geometry: (i) a mathematical model (3) which predicts ligament lengths as a function of implant geometry and motion, (ii) buckle transducers (1), which are experimental devices that provide a direct measurement of in vitro or in vivo ligament forces during functional conditions, and (iii) a three-dimensional finite element stress analysis capability (5), which can be used to investigate TKR interface stresses analytically.

In the initial phase of this study, buckle transducers were used in conjunction with the mathematical model to investigate cruciate ligament mechanics during flexion of knees containing prostheses with differing component geometries (2). With normal component placement and both cruciates intact, full range of flexion was restricted with a highly conforming, single-radius-of-curvature TKR design, because of large constraint forces in the posterior cruciate ligament. Ligamentous incompatibility was avoided with a multicurvature TKR design. Low conformity of components permitted anterior-posterior displacements to accompany flexion, which provided for a full range of flexion and allowed cruciate ligament forces to approach that of a normal knee. The study indicated that special precautions must be taken to avoid ligamentous constraint forces and potential tibial component loosening, when using a TKR design with highly conforming components with both cruciate ligaments present. Such information is important to the clinician, when choosing an appropriate TKR design to insure ligamentous compatibility, when faced with either one, both, or no cruciate ligaments at the time of surgery.

Another topic investigated was the role of the anterior cruciate ligament in a knee with a low-conforming, semi-constrained TKR design (4). It has been shown in a finite element stress analysis (5) that, for a given external load condition, a tibial component with one large central post (which requires routine excision of the anterior cruciate ligament) produced lower stresses at the bone/cement/prosthesis interface than a tibial component with two or three smaller posts (which allows retention of the anterior cruciate ligament). The question addressed in this phase of the study was, would routine excision of the anterior cruciate ligament alter knee-joint mechanics and thus produce high constraint forces in other ligaments as well as increasing the joint contact force, thereby negating the potential for improved fixation obtained with the central-post tibial component? Would retention of the anterior cruciate, if possible, allow normal knee mechanics to occur, producing lower ligament and contact forces, thereby increasing the potential for better fixation of the tibial component design with two or three smaller posts making it more effective than the central-post design?

Buckle transducers were installed on both cruciate and collateral ligaments of four fresh cadaver knees. A semi-constrained TKR design with a three-post tibial component (which allows retention of the anterior cruciate ligament) was implanted in each of the four specimens. Spring scales were used to apply to the specimens external load conditions which are known to load the anterior cruciate. Ligament forces were recorded by the buckle transducers. The anterior cruciate ligament was then severed, spacers were added to the implanted three-post design to tighten the joint (thereby simulating a central post tibial design). The same load conditions were applied, and the ligament forces recorded. It was found that, on the average, collateral ligament forces doubled in magnitude after excising the anterior cruciate ligament, also implying that the implant contact forces increased.

To take into account the joint contact force, a simplified analytical force analysis was performed which included the anterior cruciate and collateral ligament forces, the external load condition, and contact force at a predetermined contact point on the TKR articulating surface. The analysis was designed to compare contact force and collateral ligament force magnitudes for the cases of with/without the anterior cruciate ligament, for a specific contact point. The results indicated that, over a series of arbitrarily chosen contact points, the contact force magnitude was on the average 2.5 times greater when the anterior cruciate ligament was excised, while the collateral ligament forces were on the average 6.2 times greater.

These results create the suspicion that the supposed advantage of increased fixation with the central post tibial component design could be negated because of the higher contact forces which arise due to the absence of the anterior cruciate ligament. Definitive conclusions cannot be made at this point, however, because contact point location information has been ar-

bitrarily chosen, but not analytically or experimentally determined.

Based upon the ligament investigations, an improved orthotic knee joint and knee orthosis have been designed to provide joint stability required by TKR patients with excessive ligamentous insufficiency. The geometry of the semi-constrained orthotic joint allows complex TKR motions to freely occur, yet stability for cruciate or collateral instability is provided when needed by the sequential tightening of specific sets of inextensible straps crossing the orthotic joint. The basic design has been finalized. A series of clinical trials has been initiated, and an evaluation protocol developed, so that TKR patients receiving the proposed orthosis can be completely evaluated at a future date. A laboratory test has been completed which demonstrates the advantages of the proposed orthotic joint over other commercially available joints, especially for the TKR application.

With regard to the question of anterior cruciate ligament retention in a semi-constrained TKR, refinement of the experimental procedure is required before definitive conclusions can be made. In the previously described work, the contact point has either been neglected or chosen, but neither experimentally nor analytically determined for the external load conditions with/without the anterior cruciate ligament. Such data is necessary because the ligament and contact force information will be used as input for a stress analysis, which will yield the ultimate comparison of TKR designs in terms of interface stresses (potential for loosening). Contact point information will be provided by using a six-degree-of-freedom electrogoniometer, which is currently being developed in our laboratory. The same experimental procedure previously described will be followed, with ligament forces from buckle transducers and TKR contact point locations from the electrogoniometer being used in an analytical force analysis to determine subsequent TKR contact force magnitudes. Ligament and contact force information will then be used as input for a three-dimensional finite element stress analysis of the TKR component designs. The effect upon the tibial interface stresses (potential for loosening and subsequent failure) of using TKR components with/without the anterior cruciate ligament can then be determined definitively.

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The Texas Rehabilitation Engineering Center at TIRR contributes to rehabilitation engineering service delivery and studies the effects of pressure on tissue and strategies for the prescription of wheelchair cushions to minimize the risk of pressure sores.

Handcrank Ergometer

As part of the Texas Rehabilitation Engineering Center research utilization, the REC and the VA Hospital-Houston, through a cooperative project, have developed an accurate, compact, mobile, multi-usage handcrank ergometer. This upper-extremity ergometer was designed and fabricated to meet the needs of evaluating and exercising paraplegic and lower-extremity-amputee subjects. The device permits the evaluator to select a power output requirement within the range of a few watts to 500 watts for the subject. Once the power requirement and the exercise speed (approximately 30 RPM) are set, the ergometer will maintain a constant power sink regardless of variation of $\pm$ 2.5 watts.

Currently, the unit is undergoing some final detail fabrication and is available for subject testing. After preliminary subject evaluations, the design will be reviewed and modified as needed to make the system more clinically useful.

Seating Service Program

As part of the Texas Rehabilitation Engineering Center research utilization in tissue-pressure management, a new seating service program has been developed to provide adequate seating for disabled persons who need postural controls. Typically, the REC has focused its seating clinics more towards mobility-impaired persons with insensitive skin, but this new clinic will aid physically handicapped children, mainly those suffering from cerebral palsy, muscular dystrophy, and head injuries, where seating systems can enable each child to become independently mobile and to interact in the social and educational environment.

Patients are referred to the seating clinic to assess the disabilities and needs of each patient and to formulate a seating prescription which best serves these needs. To ensure that the finished system is adequate, each patient attends a follow-up session for checking and fitting.

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Introduction

The Rehabilitation Engineering Center, founded in 1971 with a grant from the Rehabilitation Services Administration, is located on the grounds of Rancho Los Amigos Hospital, a teaching hospital of the University of Southern California and one of seven hospitals administered by the County of Los Angeles. The hospital is a 450-bed facility, devoted entirely to acute rehabilitation care, that provides an effective and unique location for the development of rehabilitation technology.

During the 11-year history of the Center, functional electrical stimulation has been a major core area of research. A description of this work and that of pathokinesiology and delivery of rehabilitation engineering services can be found in the Spring 1981 issue of this Bulletin (BPR 10-35).

Correction of Spinal Deformities—J. Axelgaard, M.S. and J.C. Brown, M.D. The project description and methods and procedures in this research are described in detail in the Spring 1981 issue of this Bulletin (BPR 10-35).

To date, 144 spinal deformity patients have entered the Lateral Electrical Surface Stimulation (L.E.S.S.) treatment program. One hundred patients, or 70 percent of the cases, are classified idiopathic scoliosis. The graph in Figure 1 shows the treatment results for these patients with a follow-up of from 3 months to 4 years, averaging 13 months of treatment. The 110 curves presented in the graph are divided between 90 patients with single curves and 10 patients with double curves. As seen, this patient group on the average progressed 12° (from 17° to 29°) during the 6-month period prior to treatment, while arrest of progression with an average 2° correction is observed for the treated curves following initiation of treatment.

Of all curves with at least 3 months of follow-up, arrest of progression (between +5° and −5° curvature change) is seen in 78 percent of the cases, improvement (>5° curvature decrease) in 8 percent and further progression (>5° curvature increase) in 14 percent. In the group who experienced curvature increase, continued progression is attributed to:

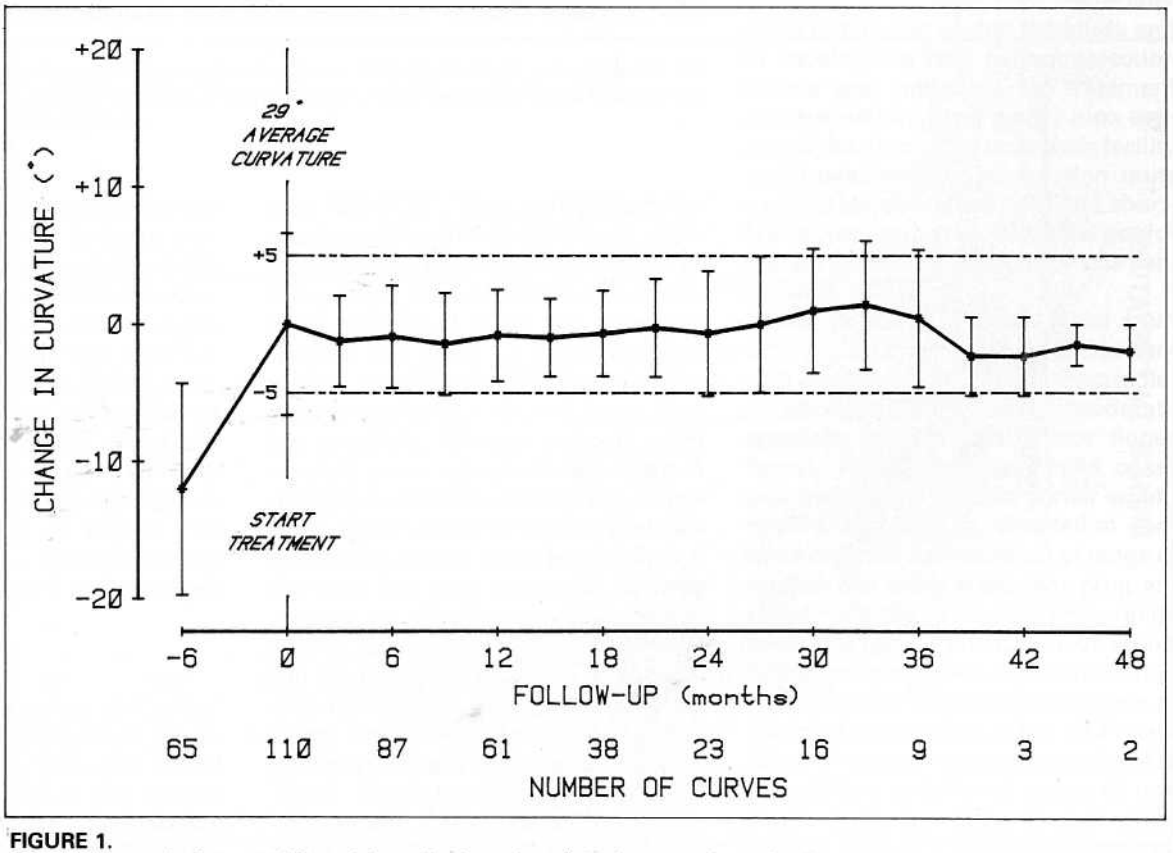

FIGURE 1.
Treatment results from 100 idiopathic scoliosis patients (single curves in 90, double curves in 10) treated with Lateral Electrical Surface Stimulation.

1. Non-compliance 6%
2. Intermittant usage due to:
   a. Skin rash 1%
   b. Electrode problems 3%
3. Treatment ineffective 4%

   14%

Statistical analysis of compensatory curvature, sagittal curvature, rib hump, spinal rotation, and apical wedging confirms earlier observations that the L.E.S.S. treatment does not have any adverse effects on the spinal anatomy. A muscle biopsy study of 12 Swedish patients who have received at least 6 months of stimulation, as well as clinical observations at Rancho Los Amigos Hospital of patients with up to 4 years of nocturnal stimulation, have not indicated any negative effects on the stimulated musculature. The only known side-effect has been skin rash near the electrodes, which can be remedied by selection of alternative electrode coupling media.

Unlike the brace treatment, a weaning period of one to several years post-skeletal maturity is not used with the L.E.S.S. treatment. The graph in Figure 2 shows that the curvature present at treatment termination does not increase during the post-treatment years.

In addition to the 100 idiopathic scoliosis patients, the following categories of patients are included in the surface stimulation program:

1. Neuromuscular scoliosis (daytime bodyjacket) .. 16 patients
2. Miscellaneous scoliosis ..... 9 patients
3. Braced idiopathic scoliosis ..... 5 patients
4. Scheuermann's kyphosis ..... 7 patients
5. Postural and other kyphosis ..... 4 patients
6. Combined deformities ..... 3 patients

The treatment results for non-idiopathic scoliosis and combined deformities resemble those obtained for the idiopathic group. The kyphosis groups, however, show an average curvature reduction of 6° over a treatment period ranging from 3 to 30 months. Five kyphosis patients have improved from 8° to 15° while curvature progression has been stopped in the other six patients.

During the past year a major effort has gone into the development of a menu-driven computerized system for data management and statistical data analysis. In order to obtain FDA approval of the L.E.S.S. treatment method and equipment, a 923 page document consisting of protocol, clinician manual, patient manual, data forms, patient data, statistical analyses, stimulator specifications, etc. has been prepared and submitted to the FDA.

In a continued effort to reduce the number of X-rays taken during treatment (brace or L.E.S.S.) as well as during pre- and post-treatment patient observation, a special rib hump measuring device and a Moire fringe topography camera has been introduced in the clinic to provide supplementary non-radiographic deformity measurements. Figure 3 shows the rib hump measuring device produced by this center for accurate and reliable measurement of rib hump and lumbar prominences. This device can also directly measure kyphosis and lordosis in any desired patient position. The

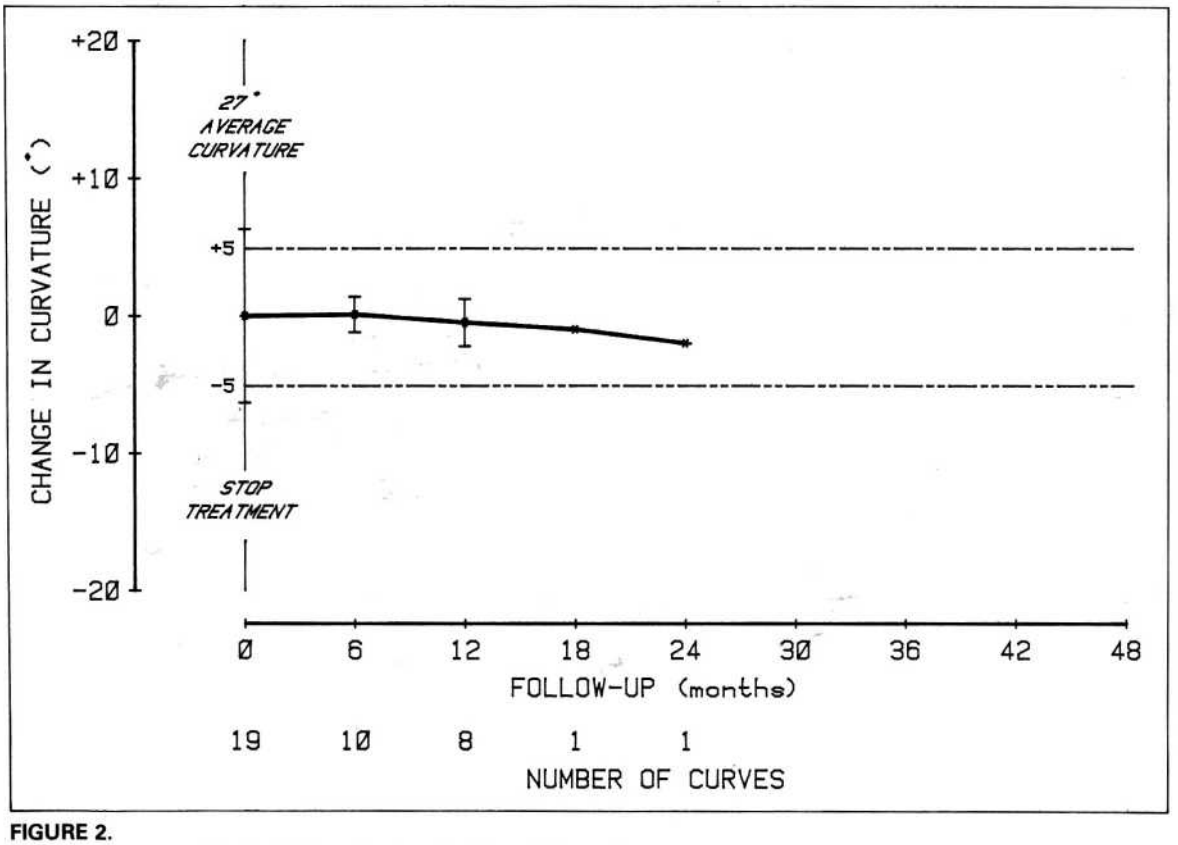

FIGURE 2.
Post-treatment results from 19 patients with idiopathic scoliosis.

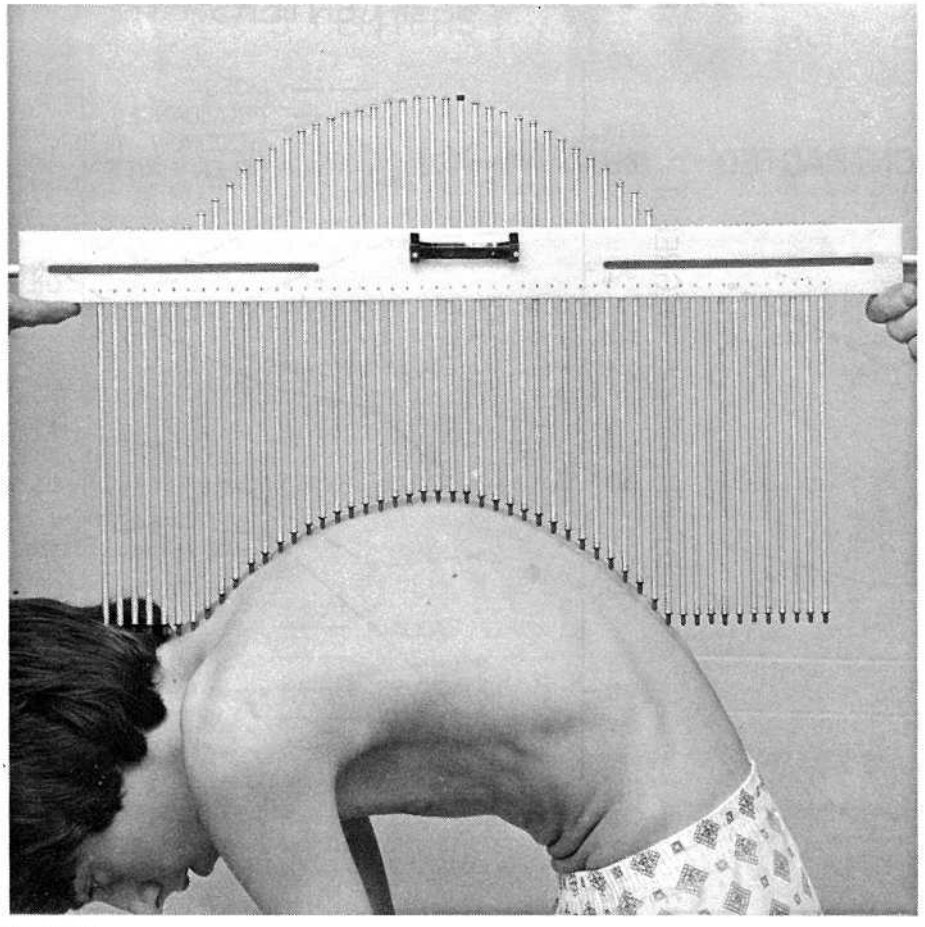

FIGURE 3.
Rib hump measuring device applied to kyphosis patient. Fifty lightweight pins spaced 1 cm apart form a contour of the patient's back. This contour is transferred by pressure to paper for later computer entry via a digitizer.

Moire camera (FM-40), provided to our center for evaluation by Fujinon, projects light through a grid onto the back of the patient to be measured. The projected grid lines form a contour pattern when photographed through a similar grid, which vividly depicts existing deformities. Initial patient testing shows high reproducibility of the Moire pictures. A computer program to quantitate the Moire patterns is presently under development. It is hoped that devices such as these will significantly reduce the number of X-rays required in the future.

Multi-Center Evaluation of Cyclical Stimulation — Bruce Bowman, Sc.D., Lucinda Baker, M.S., P.T., and Laurel Benton, P.T. The goal of this project was to verify at other rehabilitation centers the results of a study carried out by this institution in 1976 (VA contract 101 (134)). The original study investigated the clinical efficacy of cyclical electrical stimulation to decrease flexion contractures of the wrist, metacarpophalangeal (MP) and interphalangeal (IP) joints in sub-acute and chronic hemiplegic patients who displayed moderate wrist and finger flexion spasticity. Sixteen patients were treated, nine whose onsets were 4 months or less before electrical stimulation treatment was initiated, and seven whose onsets were longer than 4 months. The nine sub-acute patients showed no significant wrist or finger flexion contractures and maintained full joint range throughout the 4 week stimulation trial, even though traditional range-of-motion exercises and splinting were discontinued. Initially, seven chronic hemiplegic subjects demonstrated an average pre-treatment passive range of motion of 13° wrist extension and 2° MP extension. After 4 weeks of stimulation treatment, these ranges were increased to an average of 49° wrist extension and 29° MP extension.

A preliminary investigation (VA contract 790P-1092) provided the opportunity to evaluate five centers across the country for collaboration in the project. In addition, a contract with an outside manufacturer to build electrical stimulation devices was awarded to StimTech, Inc. A procedure manual detailing the use of electrical stimulation for obtaining wrist and finger extension was also included in the preliminary project.

A two-day workshop was conducted at the Rancho Los Amigos Rehabilitation Engineering Center. Two persons from each of the following five centers attended the workshop: Moss Rehabilitation Hospital, Philadelphia, Pennsylvania; Woodrow Wilson Rehabilitation Institute, Fishersville, Virginia; Helen Hayes Hospital, West Haverstraw, New York; Dallas Rehabilitation Institute, Dallas, Texas; and Providence Medical Center, Seattle, Washington. The purpose of the two-day workshop was to familiarize the therapists and physicians with the equipment to be used during the study and to develop the final patient selection criteria and protocols for treatment and evaluation. Each center also estimated the number of units their facility could use, and the stimulation units were forwarded to the hospitals shortly after the workshop. Electrical goniometers designed and built by this center were also sent.

The protocol that developed from the workshop prescribed treatment with electrical stimulation for hemiplegic stroke patients who had moderate spasticity of the wrist and/or finger flexors. Patients whose stroke onset was less than 4 months earlier would receive one or two stimulation sessions daily for maintenance of range of motion. No other treatment program aimed directly at maintaining range was to be used. Patients whose stroke onset was more than 4 months earlier would receive two to three sessions of electrical stimulation a day, and again all other treatment programs aimed at maintaining or gaining range of motion would be discontinued. Both groups would be treated for 4 weeks, with passive wrist flexion and exten-

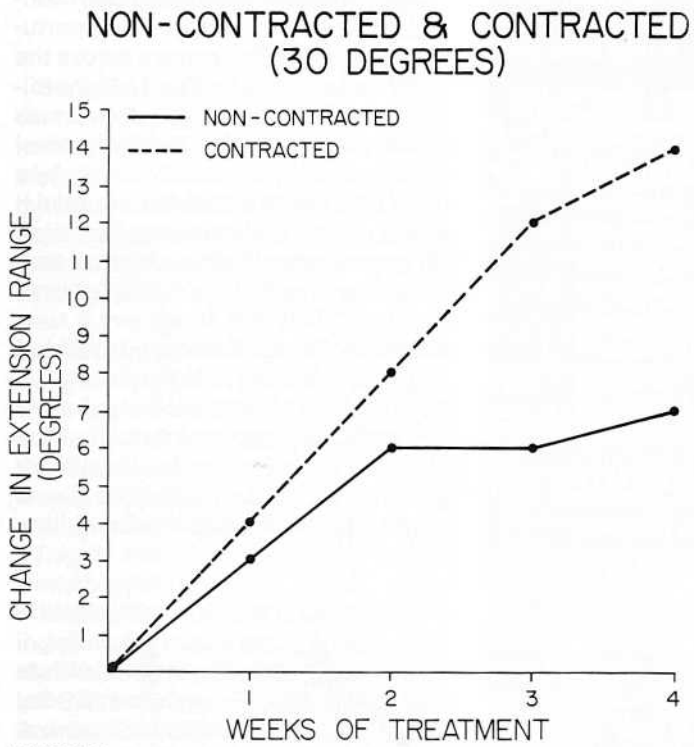

FIGURE 4.
Non-contracted groups. The contracted group, starting with an average of 22 degrees of passive extension, gained 14 degrees during the four-week cyclical stimulation treatment. The non-contracted group started with 52 degrees and not only maintained their range, but gained seven degrees.

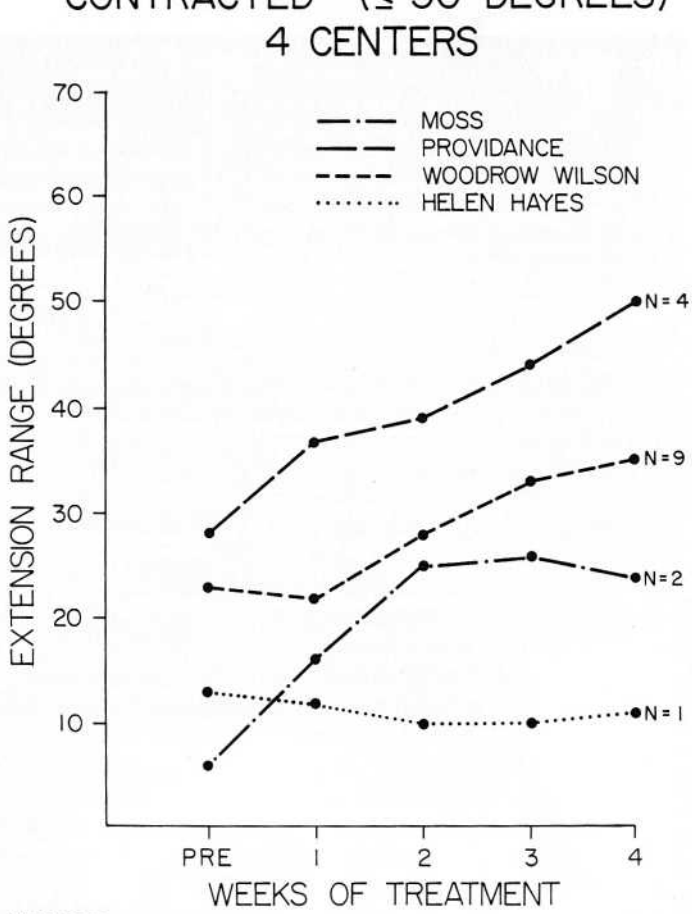

FIGURE 5.
Average extension range for each center—contracted group. Only one center failed to report success in pulling out wrist flexion contractures using cyclical electrical stimulation. This center had only one patient in the contracted group which consequently had little influence on the overall positive results.

sion monitored weekly using the electrical goniometer.

In total, 85 patients completed the 4 week treatment program at the five participating institutions. Thirty-six of the patients had the onset of their strokes less than 4 months prior to the initiation of the treatment and were classified as acute. Forty-eight patients were classified as chronic, with more than 4 months elapsing between the stroke and the stimulation treatment. While it was anticipated that a high percentage of chronic stroke patients with moderate spasticity would have developed flexion contractures, only 16 patients demonstrated extension range limited to 30° or less. Since time following onset of the vascular insult was not highly correlated with soft tissue restriction, the classifications contracted and non-contracted were used in reporting data.

Patients were classified as contracted if they had less than or equal to 30° of passive extension range prior to treatment. The 16 patients who fell into this category had a mean time since onset of nearly 4½ years. As can be seen in the dashed line in Figure 4, these patients on the average made progress throughout the 4-week treatment program and were still improving at the termination of the study period. They started the program with just over 20° of extension and finished with more than 35°.

The remaining 69 patients had greater than 30° passive extension range prior to the program and were classified as non-contracted. As shown by the solid line in Figure 4, these patients not only maintained their range, but also made some progress during the 4 week program. These patients started with just over 50° of extension and finished with nearly 60° on the average.

Extension range data is broken down by the participating hospitals in Figure 5 for the contracted patients and in Figure 6 for the noncontracted patients. The patients with the longest-standing flexion deformities were treated by Woodrow Wilson Rehabilitation Institute, and it can be seen from Figure 5 that the Woodrow Wilson patients required more than a week of treatment before progress was noted. Patients treated by the other participating centers generally did not have such a long history of disability and deformity, and it can be seen that those treated at Providence Medical Center and Moss Rehabilitation Hospital made rapid improvements. As shown in Figure 6, the noncontracted patients at each hospital were able to maintain their range fairly consistently throughout the 4 week treatment period.

Two centers treated 25 patients as outpatients, with most of these classified in the chronic group. In fact, nearly half of the chronic patients were treated as outpatients during the last part of their program. These patients aver-

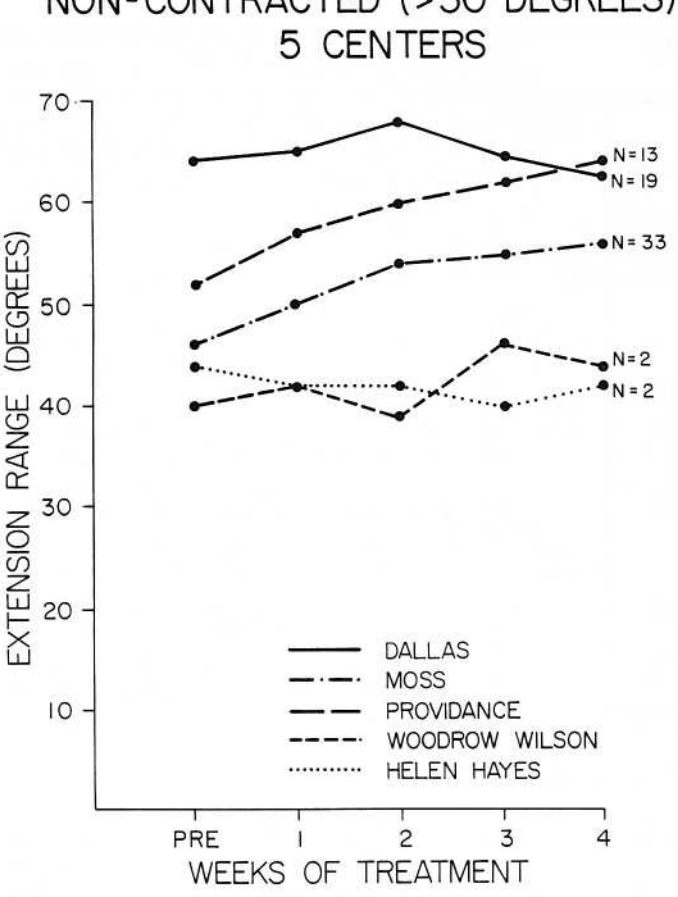

FIGURE 6.
Average extension range for each center—non-contracted group. All centers reported success in at least maintaining range using cyclical electrical stimulation on patients with moderate spasticity.

aged 13° of increased range of motion and were essentially indistinguishable from their peers treated within the hospital setting.

Although the use of electrical stimulation was new to three of the centers participating in this study, there was little difficulty with equipment. Though patients occasionally missed a day of treatment or one session during a day, no patients were discontinued from the project because of prolonged equipment failure.

The results of this study are very similar to those reported in the initial evaluation at Rancho. All centers were successful in maintaining range of motion in those patients displaying full passive range prior to the stimulation program.

Few problems were encountered with the stimulators and goniometers, indicating that efforts to build reliable hardware for clinicians with minimal technical training were successful. The fact that most of the participating centers used their equipment intensively for varying lengths of time also indicates that the therapists had sufficiently high tolerance for the 'gadgetry', and could successfully develop treatment programs around the available equipment to optimally meet the patients' needs. Three centers manned their stimulation research programs with physical therapy personnel, while the other two centers assigned occupational therapists to carry out both treatment and measurement.

Energy Costs of Normal Walking — Robert L. Waters, M.D., Helen J. Hislop, Ph. D., Lynn Thomas, M.A., R.P.T., and Joyce Campbell, M.A., R.P.T. Energy cost studies have proven a valuable method of determining the physiologic penalties imposed by abnormal gait. There was a need to establish normative standards on the energy cost of walking for normal subjects of all ages, to which the energy cost of individuals with physical gait disabilities can be compared. Hence, a comprehensive study encompassing a large population of male and female subjects 6 to 80 years of age was undertaken to provide the needed data.

Two hundred and twenty-five subjects between the ages of 6 and 80 years were tested. The subjects were divided into four groups: children (age 6–12 years, N=61); teenagers (age 13–19 years, N=53); adults (20–59 years, N=47); and seniors (age 60 years and over, N=64). In selecting subjects, emphasis was given to the younger and older groups, because the energy demands of walking in young adults has already been reported in the literature with consistent results.

All testing was done on a level outdoor track, 60.5 meters in circumference. Heart rate, respiratory rate, and step frequency data were telemetered via an FM-FM VHF radio transmitter system from transducers attached to the subject. Expired air was collected by a modified Douglas bag system having a two-way "J" valve at the mouthpiece. A three-way valve at the neck of the collection bag allowed the investigators to begin gas collection without interrupting subject performance after steady state was achieved. The weight of the entire system, carried on a chest harness, was less than 2.5 kilograms.

After becoming familiarized with the gas collection system, subjects were asked to walk at their customary walking speed. When they reached steady state (generally within 3 to 5 minutes), as evidenced by plateaus of heart rate and respiratory rate, a 2 minute period of gas collection ensued. All gas volumes were expressed in STPD units.

The rate of oxygen uptake was significantly higher in children and adolescents than in adult or senior subjects. The average value for children, 15.3 ml/kg-min, was significantly greater ($p<.0005$) than for teenagers, 12.9 ml/kg-min. Both were significantly greater ($p<.005$) than the values for adults and senior subjects which were the same in both groups, 11.9 ml/kg-

		Children (6-12 yr)	Teenagers (13-19 yr)	Adults (20-54 yr)	Seniors (60-80 yr)
Rate O_2 uptake (ml/kg-min)	M	15.8 ± 2.1*	13.2 ± 1.9	12.0 ± 2.2	11.9 ± 1.9
	F	14.5 ± 2.8*	12.6 ± 1.7	11.7 ± 2.3	11.8 ± 1.6
	MF	15.3 ± 2.5	12.9 ± 1.8+	11.9 ± 2.3+	11.9 ± 1.7
Net O_2 cost (ml/kg-m)	M	.23 ± .03	.18 ± .02	.14 ± .02	.16 ± .02
	F	.21 ± .04	.17 ± .02	.15 ± .02	.17 ± .02
	MF	.22 ± .03	.18 ± .02+	.15 ± .02+	.16 ± .02²
Heart rate (bpm)	M	111 ± 11*	90 ± 10*	94 ± 14*	97 ± 12*
	F	118 ± 12*	103 ± 12*	104 ± 13*	106 ± 12*
	MF	114 ± 12	97 ± 13+	100 ± 14+	103 ± 13
Velocity (m/min)	M	71 ± 8	73 ± 12	84 ± 9	75 ± 9
	F	68 ± 9	73 ± 9	76 ± 11*	71 ± 10
	MF	70 ± 9	73 ± 10+	80 ± 11+	73 ± 10+
Cadence (steps/min)	M	120 ± 8	100 ± 8*	112 ± 9*	104 ± 10*
	F	119 ± 9	107 ± 7*	116 ± 10*	112 ± 9*
	MF	120 ± 9	104 ± 8	114 ± 10+	110 ± 10
Stride length (m)	M	1.18 ± .14	1.47 ± .16*	1.51 ± .17*	1.44 ± .15*
	F	1.15 ± .15	1.36 ± .13*	1.31 ± .14*	1.27 ± .13*
	MF	1.17 ± .14	1.41 ± .15+	1.40 ± .18	1.33 ± .16+

TABLE 1

Energy expenditure and selected gait parameters during free level walking in 225 subjects, 100 males (M) and 125 females (F). Asterisk (*) indicates significant difference ($p<.02$) between males and females. Plus sign (+) indicates significant difference ($p<.02$) from preceding younger age group for combined male and female subjects.

min. (See Table 1 for a compilation of these and other data). The only difference related to sex occurred in the children's group; the mean value for males, 15.8 ml/kg-min, was significantly greater ($p<.05$) than the average for females, 14.5 ml/kg-min.

The oxygen consumption per unit of distance walked did not differ between males and females, but was dependent on age. Oxygen cost per meter averaged .22 ml/kg-m for children which was significantly greater ($p<.0005$) than for teenage subjects, .18 ml/kg-m. Both values were significantly higher ($p<.0005$) than the average values for adult subjects, .15 ml/kg-m. The average for senior subjects, .16 ml/kg-m was also significantly greater ($p<.0005$) than the mean for adults.

Heart rate was significantly higher ($p<.05$) in children than in all older subjects. The mean value for children was 114 bpm; for teenagers, 97 bpm; for adults, 100 bpm; and for senior subjects 103 bpm. Mean heart rates among the three older groups were not significantly different. In each age group, the mean heart rate for females was significantly greater than for males. The difference in the mean values between males and females was 7 bpm in children, 13 bpm in teenagers, 10 bpm in adults, and 9 bpm for senior participants.

The mean individually selected walking speed was highest in the group of young adults. The value for teenagers, 73 m/min, was significantly greater ($p<.025$) than for children, 70 m/min. The value for adults 80 m/min, was significantly greater ($p<.005$) than for teenagers and for seniors ($p<.0005$) who averaged 73 m/min. Velocity varied between men and women only in the adult group, where men walked at 84 m/min, in contrast to the mean rate of women of 76 m/min, ($p<.025$).

The data indicates that the mean values for rate of oxygen uptake per minute, oxygen cost per meter, and heart rate, gait velocity, cadence, and stride length during normal level walking depend on age and sex. Standards for adult subjects should not be used for children, adolescents, or senior subjects over the age of 60 years.

Kinesiology of the Total Knee Arthroplasty in Rheumatoid Arthritis—Jacqueline Perry, M.D., Ron Greenberg, M.A., R.P.T., and J. Mulrand, M.D. The purpose of this study was to measure, in the Pathokinesiology Service at Rancho Los Amigos Hospital, the preoperative and postoperative passive and dynamic (during gait) range of motion and to record stride characteristics in those patients who underwent various types of total knee arthroplasties. A comparison was also made between patient groups receiving different types of implants.

Fifty-two patients were evaluated preoperatively and postoperatively, some bilaterally, totalling 68 total knee arthroplasties. Only six patients were male. The mean age was 57.1 years. Postoperative evaluation was done 6 or more months after surgery, averag-

ing 17 months. Patients were grouped into four categories, depending on type of implant used. Stability, alignment, the presence of a flexion contracture, and the availability of newer designs determined the preference of the various implants. The categories consisted of:

1. Total condylar and duopatellar, 26 patients (34 procedures)
2. Geometric, 15 patients (19 procedures)
3. Marmor and Polycentric, 7 patients (10 procedures)
4. Attenborough and Guepar, 4 patients (5 procedures)

A footswitch system consisting of bilateral insoles with compression-closing sensors under the heel, 5th metatarsal, 1st metatarsal and great toe was used for basic stride characteristics. The pattern of knee flexion and extension occurring during walking was measured with an electrogoniometer consisting of a double parallelogram connected to a linear potentiometer. A Cybex II machine was used to measure knee extension force at a fixed angle of 60° flexion (isometric) and over the entire range of knee extension (isokinetic) at 15°/second. Ankle plantarflexion force was measured with an electric ring tensiometer affixed to the ceiling by a chain and connected to a foot support under the metatarsal heads. The Harris clinical rating system, modified in this study for the knee, documented the patients' pain, function, deformity, and range of motion (ROM). There were 95 points possible.

All statistical analysis was performed on a PDP 11/34A minicomputer. Paired t-tests were used to compare pre- and postoperative results. Minimal level of significance was $p<.05$.

All groups made statistically significant gains postoperatively except for the small group (4 patients) receiving Attenborough and Guepar prostheses. This latter group will be discussed separately. The following results refer to the three major implant groups.

Stride Characteristics: Gait velocity, cadence, stride length, and single stance time significantly improved following total knee replacement. Preoperative to postoperative mean values were as follows: Gait velocity—35% of normal to 55% of normal (Figure 7); cadence—75 steps/minute to 93 steps/minute; stride length—.70 meters/stride to .89 meters/stride; and single stance time—58% of normal to 76% of normal. The group with Marmor and Polycentric implants had relatively higher scores than the other two groups both pre-and postoperatively.

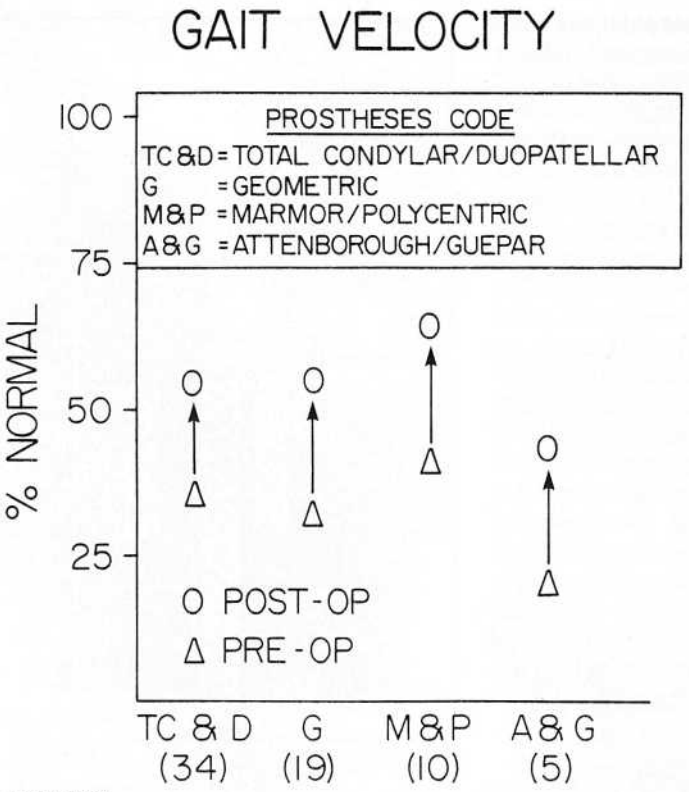

FIGURE 7.
Comparative walking speeds of four implant groups.

Passive ROM: There was a significant shift in the arc of passive ROM postoperatively toward more extension and less flexion. Reduction in the knee flexion contracture went from an average of 17° to 40°. This gain was offset by a loss of flexion beyond 90° postoperatively. The result was a nonsignificant change in the total ROM but a significant reduction in the knee flexion contracture. Postoperatively, the three groups were markedly similar in arc of passive knee motion.

Dynamic ROM: Knee motion during gait increased significantly postoperatively (Figure 8). The dynamic motion preoperatively was a mean of 15° (range 12° – 29°). This increased to 37° (range 35° – 41°) postoperatively. The dynamic terminal extension range preoperatively lacked 25° of full extension. This increased significantly to within 5° of full extension, postoperatively. The rate of knee flexion during swing phase increased significantly from a mean of 83°/sec to 207°/sec. Knee flexion during weightbearing (loading response) also displayed a significant increase, from a mean of 2° preoperatively to 5° postoperatively. Knee position at initial foot contact (beginning loading response) averaged 20° preoperatively and was significantly decreased postoperatively to 5°. Postoperatively, the dynamic ROM in the three groups had similar outcomes. Patients with Marmor and Polycentric prostheses (3rd group) had slightly better values both preoperatively and postoperatively.

Torque Values: Knee extension capability significantly increased after total knee replacement. Average preoperative torque was 14% of normal improving to 30% of normal postoperatively. Ankle plantar flexion torque did not change with total knee replacement surgery in any of the groups.

Harris score: The Harris score, a combination of pain, range of motion and function, registered significant gains postoperatively, advancing from a preoperative average of 39 points to 69 following surgery. Outcomes for the 3 groups were similar even though the group with Marmor and Polycentric prostheses scored higher

preoperatively.

Results of Attenborough and Guepar Implant Group: This group of 4 patients (5 procedures) showed no significant improvement in range of motion, stride characteristics, force and Harris scores except as follows: dynamic swing flexion of knee from an arc of 6° preoperatively to an arc of 33° postoperatively (Figure 8); knee flexion during weightbearing (loading response) improved from 1° preoperatively to 5° postoperatively; and cadence improved from 64 to 88 steps per minute following surgery. No strength testing was done in this group.

By standard clinical testing, gains following total knee joint replacement have been difficult to demonstrate because there has been no significant change in the passive range of motion. This is true in this study and has been previously reported by other investigators. With dynamic electrogoniometry, however, it was demonstrated that the patients experienced marked improvement. Postoperatively, the motion they used during walking was more than double the preoperative value. More importantly, the postoperative dynamic motion occurred in a more functional arc. Preoperative average dynamic knee motion lacked 25° of full extension while postoperatively only an average of 5° was lacking for full dynamic extension. The fact that the gain in the rate of knee flexion tripled while walking speed doubled identified absolute improvement in knee joint mobility.

From such findings it became evident that gait measurements were a valuable means of judging patients' progress. Functional gains were identified which could not be elicited by clinical measures. Also, rheumatoid patients still are significantly disabled with a mean postoperative velocity only 55% of normal, and thus it often is difficult to appreciate the functional progress they have made since surgery without objective gait measurement.

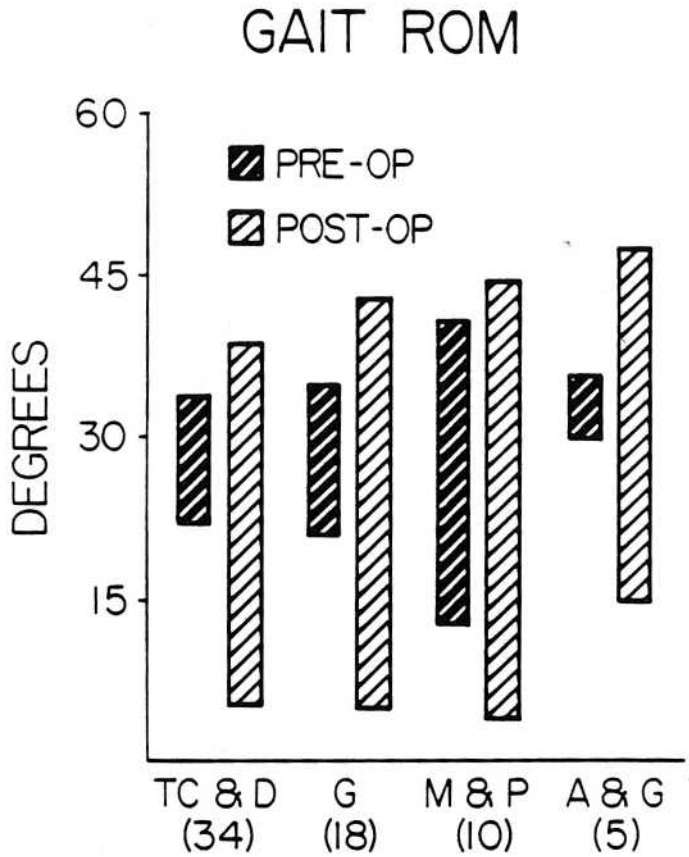

FIGURE 8.
Dynamic range of motion of the knee during walking.

Automated Zoom Angle Control System—Daniel Antonelli, M.D., and Hiroshi Yoshida, M.S. The objective of this project is to design and build an automatic zoom lens control system which would preserve constant image dimensions on a video screen of a subject walking toward or away from the camera. An automated ranging system will enable the semiautomated vector analysis system now under development at the Pathokinesiology Service, to perform three-dimensional gait analysis.

The proposed system is shown in Figure 9. Range information is derived from the Polaroid Ultrasonic Ranging Unit. An electrostatic transducer acts as the transmitter and the receiver of subsequent reflectons. It is desired that the camera (with zoom) maintain the subject's image at a constant and conveniently large size on the screen independent of the distance of the subject from the camera (l−5) over the range l=10 to 40 ft.

A vertical object 3'3" long was placed at a sequence of measured distances from the camera, and the angle of an indicator geared to the zoom lens was set at the value required to maintain the image height constant at each distance. It was determined that the relationship is logarithmic and is given by:

lens angle (in degrees) =206.9 log (l-5)-138.6.

A logarithmic amplifier and circuit with parameters set to those given in this equation are used to convert distance into the desired angle voltage.

Figure 10 shows the error-deriving circuit. A multiturn potentiometer geared to the lens is used to change the lens angle into a feedback voltage which (after amplification to insure a steady constant of proportionality to lens angle) is subtracted from the desired angle voltage. The output voltage is thus the error voltage which drives the position-control servomechanism.

Polaroid claims that the maximum range of their ranging unit can be 35 ft., but our tests indicate that a usable signal is obtained only up to 27 ft. If a subject wears soft fabrics, that range can be as short as 10 ft. due to absorption of the ultrasonic signal.

A static performance test of the automated zoom angle control system was conducted. A distance between two

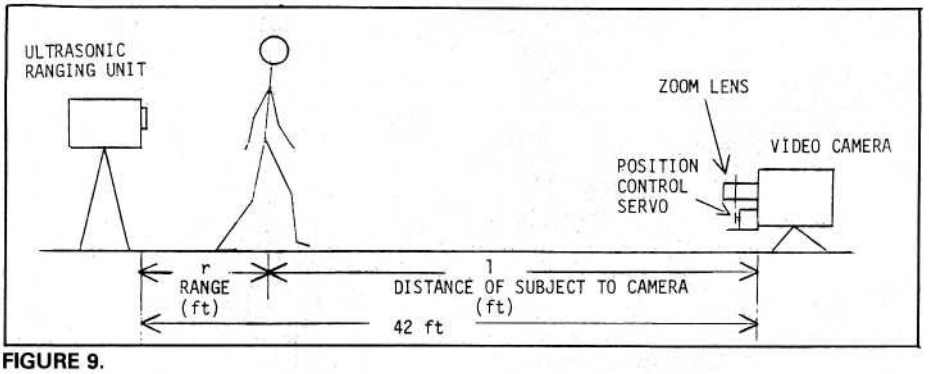

FIGURE 9.
System set up.

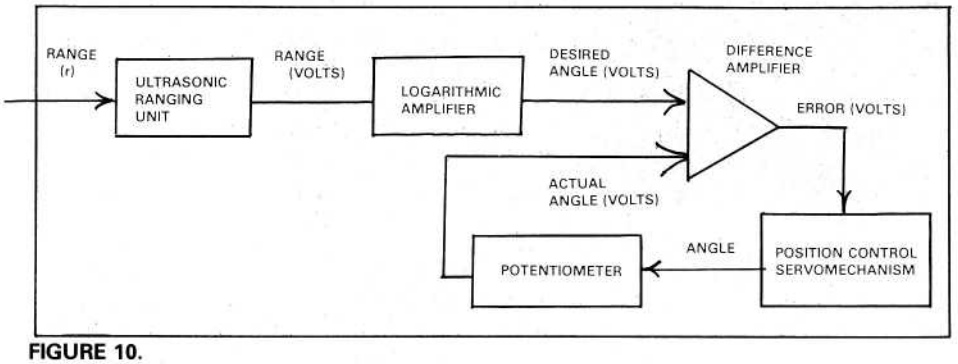

FIGURE 10.
Error deriving circuit.

fixed spots on a board at different ranges was measured by the Apple computer digisector. The digisector breaks the monitor screen into 256 x 256 segments. Results indicate that the deviation is less than ± 3% when the range is greater than 12 feet. Additional static and dynamic tests are planned to further characterize the system.

Project Threshold Client Services—Nancy Somerville and Heidi Pendleton, O.T.R. Project Threshold's client service program has been supported by the California State Department of Rehabilitation for the past 4 years. A new case service contract of $90,000 was awarded for the period from July 1981 through June 1982. This contract supplies funding to reimburse the Rehabilitation Engineering Center for providing services to a minimum of 80 clients.

Project Threshold was designed to assist severely disabled individuals in gaining independence with performance of tasks related to daily living, school or work. This program offers consultation and evaluation in these areas to identify problems preventing the individual from achieving his or her maximum level of independence. Once problems are identified, possible solutions are investigated. The specific services provided through this program are:

- Functional evaluation to determine client's abilities.
- Evaluation of client's problems with independent living, work, or school related tasks.
- Consultation regarding appropriate commercially available equipment.
- Consultation regarding feasibility of custom devices and fabrication of equipment.
- Modification of commercially available equipment.
- Design and fabrication of custom equipment.

Project Threshold uses a comprehensive assessment and problem solving approach to provide simple and cost effective solutions to identified problems. Solutions generally include: suggestions for adaptive behavior, recommendations for commercially available technology, and design and fabrication of custom equipment. The majority of solutions to problems presented by clients of the program, however, include recommendations for adaptive behavior and commercially available assistive devices. Custom devices are considered only when all other options have been ruled out.

During the past decade there has been a tremendous increase in the number of commercial products designed and developed specifically for use by persons with physical disabilities. It is our experience that appropriate application of these devices can make an amazing impact on a person's independence with daily activities. Considering the vast array of such devices and frequent changes in manufactures and distributors, it is extremely difficult for consumers and allied health professionals to know what is available. Project Threshold utilizes a variety of references and resources when searching for appropriate equipment, including books and periodicals, a comprehensive file of catalogues and brochures from equipment manufacturers, and ABLEDATA, a national computerized data file of equipment.

Once a functional evaluation of the client is completed by the Project Threshold staff, research is conducted for equipment items which seem suitable. The client is then provided with the opportunity to try out the equipment with appropriate training. In our experience, equipment trial is essential to insure that the equipment ultimately recommended for purchase is the best choice to solve the client's particular need. Many items are available in-house, but it has been our experience that many manufacturers and distributors are quite willing to provide specific equipment for use in the evaluation.

During the period February 1981 through January 1982, 67 clients were referred to Project Threshold by Department of Rehabiltation counselors. Forty-one additional clients, referred prior to February 1981, also received services during this time. Generally, these clients had severe physical disabilities, were living in community settings and were no longer actively involved in rehabilitation programs. The following case example is presented to illustrate the approach used by Project

Threshold personnel in identifying and solving problems of clients.

A 24-year old female with arthrogryposis was referred to Project Threshold by her Department of Rehabilitation counselor for evaluation to improve function and save energy in home and job activities. She has essentially no use of her upper extremities and has taught herself to do the majority of activities of daily living with her mouth. She ambulates independently, but uses a wheelchair for long distances. She is employed full-time as a keypunch operator, creates jewelry for a local boutique, attends college part-time, collaborates with her husband on homemaking chores and, at the time of referral, was expecting her first child.

The evaluation process by Project Threshold included a home visit, a job site visit, and two sessions at our Center to analyze task performance and assess equipment needs. Although the client was quite successful in performing daily activities both at work and home and was innovative in her ideas of caring for her child, the following problems were identified:

1. Excessive wear on T.S.'s front teeth from lifting and manipulating objects in her mouth, especially pencils which she used extensively at work for writing and keypunching.
2. Neck and back strain caused by uncomfortable postures required to position her head close to items, particularly during kitchen and work activities.
3. Assistance required for bathing and dressing activities.
4. The necessity to position her face close to flame and hot surfaces while cooking with standard utensils in her mouth.
5. New role as mother created many new problems limiting her ability to adequately and independently care for her soon-to-be-born child.

After problems were identified, equipment resources were explored to provide solutions. Commercially available devices recommended included a bath transfer bench to enable her to get into the tub/shower independently, suction brushes positioned on the shower wall, a long handled bathing sponge and a grab bar for independent bathing. To improve function in the kitchen, a cutting board with stainless

FIGURE 11.
An elevated work surface fosters good body mechanics for this client during food preparation. In addition, a standard paring knife modified with a V-shaped mouthpiece minimizes wear on teeth.

FIGURE 12.
Wooden crib rail modified to open like a gate allows easy access to baby. Locking lever on bottom of rail is managed with knee motion.

steel nails and corner guard to stablize food while using utensils in her mouth, non-skid surface pads to stabilize items, and various kitchen organization devices to improve homemaking efficiency and conserve energy were identified. Devices for child care included plastic-coated cuff holders to strap on to baby bottles for mouth-holding and various styles of baby equipment best suited to her needs.

Several of the client's needs were not met by commercial products, and custom equipment was designed and fabricated by Project Threshold. For both home and work tasks, custom mouthsticks with convenient docking devices enable T.S. to maintain better upright sitting position, reducing neck strain. V-shaped mouthpieces allow more precise control of the mouthstick and distribute weight more evenly on her teeth. These V-shaped mouthpieces were also added to frequently used kitchen utensils, some of which were lengthened to keep her face away from hot items (Fig. 11). Elevated table surfaces for kitchen and table top activities were a simple custom solution to reducing neck strain and fostering good body mechanics. For her job, a tubular suction operated mouthstick and vertical file bin allowed greater ease in picking up computer cards, eliminating the need to stand for better access to materials and equipment. A plastic rubber band holder was designed to allow T.S. to use a mouthstick to slip rubber bands on and off computer cards inserted into a device.

In planning for the expected baby, the client's wooden crib was modified for easier access by cutting one side rail in half, hinging both sides and reinforcing the crib frame for stability (Fig. 12). The client utilizes knee motion to open the latch. The crib provides a safe, convenient work height for changing and bathing the baby.

T.S. has since had a baby girl and manages child care with minimal assistance from her husband. She returned to work full time and is using the equipment at home and on the job. This case is an example of a person who was functioning quite well prior to professional intervention, but who was still able to benefit greatly from equipment designed to improve the quality of performance in daily activities.

Rehabilitation Engineering Center Children's Hospital at Stanford 520 Willow Road, Palo Alto, California 94304

Maurice A. LeBlanc, Project Director

Core Area of Research

This is ongoing research with focus on research on "Controls and Interfaces for Communication and Other Systems for Severely Physically Disabled People." The area was chosen because: (i) it is important and has not been approached comprehensively; (ii) it relates to many of the center's client services, from which needs are generated and where subjects for clinical evaluation can be found; and (iii) communication devices, mobility aids, and environmental control systems have controls, but little attention has been given to "mixing and matching" controls and aids/systems from different manufacturers so that one control can operate several aids, or one control can be switched among aids.

Direction of Work

The third year of the project has just been completed. The project was initiated by conducting a survey to determine what controls existed, what controls were being developed, and what controls were needed. That survey produced a wave of activity which has resulted in: (i) preparation, publication, and distribution of a catalog of controls commercially available in the U.S. and abroad; (ii) preparation, publication and distribution of a directory of R&D projects on controls (i.e., "who's doing what" in research); (iii) information from which the center is able to make rational decisions of where to focus its own R&D effort, and about what controls developed in other places ought to be clinically evaluated here.

Thus, much of our work-to-date has been "software" rather than "hardware" to determine for ourselves and others what the state-of-the-art is, and where to jump in. An obvious need will still exist for dissemination of information, but the project will become more R&D hardware intensive, to develop and test specific needed controls for the severely physically disabled population.

The work under this project is divided into several areas, which are:

- Research and Development Activities
  - Development of Controls Evaluator and Trainer Kit
  - Development of Control Simulator
  - Assessment of Control Sites
  - Standardization of Controls and Interfaces
  - Special Projects
  - Augmented Feedback Spinal Orthosis
- Clinical Evaluation Activities
  - Team Evaluation of Device Effectiveness — A Retrospective Study
  - Follow-up Study on Communication Aids and Controls/Interfaces
  - Controls Ready for Clinical Evaluation
  - Clinical Evaluation of Versatile, Portable, Speech Prosthesis
- Interaction with Industry Activities
  - Catalog of Controls
  - Directory of R&D Projects on Controls
  - Transfer of Technology
- Education and Training Activities
  - Conduct Annual Rehabilitation Engineering Services Conference
  - Rehabilitation Engineering Clinical Internship
- Dissemination of Information and Research Utilization Activities
  - Publications Office
  - Information Service

Descriptions of purpose and progress on these specific areas are included in the recent annual progress report to NIHR, copies of which can be obtained by writing to the center.

Clinical Evaluation of Versatile Portable Speech Prosthesis

Maurice LeBlanc

The task is to develop and test a versatile, portable speech prosthesis for use by severely motor-impaired non-vocal people.

The Versatile Portable Speech Prosthesis (VPSP) is a synthetic-speech-output communication aid for non-speaking people. It was intended initially for severely physically limited people with cerebral palsy who are in electric wheelchairs. Hence, it was designed to be placed on a wheelchair and powered from a wheelchair battery. The VPSP has been dubbed the "Talking Wheelchair," though the name is misleading because it can easily be separated from the wheelchair.

The VPSP is "versatile" because it is designed to accept any means of single switch, multiple switch, or keyboard control which a physically limited person has the ability to use. It is "portable" because it is mounted on and can go with the electric wheelchair. It is a "speech prosthesis," obviously, because it speaks with a synthetic voice for people unable to speak with their own voices.

The project was initiated in May 1978 and completed in November 1981. One prototype unit was built and tested with users, and avenues were pursued by which to make the results of this research available to the user population.

A final report on this project to NASA is in preparation, copies of which can be obtained by writing to this Center.

Rehabilitation Engineering Center University of Michigan 208 Lay Automotive Laboratory Ann Arbor, Michigan 48109

John W. Melvin, Ph.D., Director, David H. Harden, M.S., Project Manager, Jolan Cossairt, Project Editor/Writer

Personal Licensed Vehicles for the Disabled

Research efforts of the University of Michigan Rehabilitation Engineering Center (UM REC) focus on a number of factors related to the driving of personal licensed vehicles by persons with disabilities. Some recent progress in these areas are noted below.

Assessment of Performance Capabilities

Investigator: Devinder Kochhar

The dynamic driving simulator for handicapped driving candidates has been developed and interfaced with computer-generated dynamic road graphics depicted on a small black and white television screen. Data are now being gathered by testing persons with disabilities. Ten subjects with different disabilities (but all with impaired perceptual function) were tested to obtain longitudinal information on the learning/training effects of the simulator. The testing with the driving simulator involved the conduct of two psychomotor tasks. A central task focused on lane keeping and a peripheral task on the perception of and response to peripheral stimuli. The data include time-based recordings of a random wind disturbance, the steering wheel angle, driver lane position error, driver heading angle and response latency to the randomly appearing peripheral stimuli comprising the secondary task. Each subject was tested on five different occasions over a period of approximately 3 weeks.

When the data recordings and analysis are completed, the methodology and criteria developed will facilitate identification of persons with non-progressive disabilities who have the potential to become drivers.

Design and Development of Vehicle Adaptive Devices and Systems

Investigators: Robert C. Juvinall, Mohamed Y. Zarrugh, David H. Harden

The "door-mounted chair" system developed by the UM REC provides access for a specially built wheelchair through the door on the driver's side of an Oldsmobile Omega. Progress is continuing on the design and development of a practical system that will enable a severely disabled person to drive a passenger car from a wheelchair. One of the main refinements underway separates the chair support frame from the door itself. This frame is to be anchored to the floor of the vehicle and will allow the retracted wheelchair to swivel into the vehicle. This refinement accomplishes two objectives: (i) accommodating a larger person and (ii) minimizing irreversible modifications to the vehicle itself. Design and detailing of the new attachment and entry frame are complete. Construction of the prototype will begin shortly and should be ready for display at the 1982 Rehabilitation Engineering Conference in Houston.

Stability Requirements of Steering Systems

Investigator: Mohamed Y. Zarrugh

A new study was added this year on the stability requirement of power steering systems used by persons with disabilities for different steering modes, ranging from parking maneuvers to maintaining straight heading at highway speeds. Adaptation of conventional power-assisted steering systems to the capabilities of severely disabled drivers requires (i) reducing driver effort required to turn the steering wheel and (ii) reducing the range of steering wheel motion by reducing the gear ratio. This reduction, although desirable at low speeds, produces unnecessary sensitivity which taxes the attention of the disabled driver at high speeds and reduces the stability margin of the system. Through a simplified closed loop computer model of the driver/vehicle system, the effects of steering ratio and driver time delay are being investigated. Preliminary results show that a driver time delay greater than 0.4 sec or a gear ratio smaller than 8:1 renders the model unstable. An instrumented van and a bench testing system are being developed to augment the model and establish design requirements of a suitable system.

Improvement of Driving Performance of Persons with Brain Damage

Investigators:
Michael Sivak,
Paul L. Olson,
Donald L. Henson

Past preliminary studies have indicated that prospective drivers with brain damage might benefit from perceptual training. The current research will test this finding with a larger sample and will be related to specific questions of concern. What is the role of etiology of brain damage in determining the success of the perceptual training? What are the longer-term benefits of the training? How may training materials be individualized in order to optimize the success of the training?

During the winter of 1981 a group of persons with brain damage indicated an interest in participating in the study. In the spring of 1982, potential subjects will be screened to determine which persons exhibit perceptual deficits of interest. Those who do will be included in the main study in the summer of 1982; this study will investigate the potential for the improvement of driving performance through perceptual training.

Pre-Driving Skills for Persons with Brain Damage

Investigators:
Donald Kewman,
Charles Seigerman,
Donald Henson

It has been recognized that persons with brain damage are often unable to benefit from traditional driver education programs. Therefore, preliminary open road and closed driving courses for the driver assessment of this population were developed. The actual training sessions were conducted on a scaled-down closed driving course with an AMIGO wheelchair.

A pilot study was designed to test the hypothesis that training with the AMIGO would have a positive effect upon driving a regular automobile in persons with brain damage. Traffic stimuli such as road signs and simulated traffic conditions were built into the program. As a result of this pilot study, certain changes were made in the AMIGO training vehicle.

A modified AMIGO wheelchair which incorporates the basic features (steering wheel and foot controls) of an automobile was used for this study. Other modifications in the program include a system which provides for accurate timing of each subject's performance on training tasks and allows for the systematic presentation of driving-related visual stimuli which are used in decisions and directed attentional tasks.

A group of four subjects with diffuse brain damage have begun evaluation/training procedures with the modified equipment. The evaluation/training will accommodate 18 more persons through the summer of 1982. A group of approximately 10 non-brain-damaged subjects will serve as a control group for several of the training tasks.

Current plans call for the training of up to 20 persons so that a critical evaluation of the efficacy of this program can be made. At the end of the training sessions, the data collected will be analyzed. If the training program proves to be effective, the procedures and equipment utilized in the program will be made available to the rehabilitation community.

Vestibuloocular Dysfunction

Investigators:
T. Dean Clack,
Wanda Milburn

Work of the group studying Vestibulloocular Dysfunction among Deaf Drivers was reported in the Spring 1981 issue of the Bulletin of Prosthetics Research (p. 254). At that time, they had demonstrated that otolithic insufficiency has a deleterious effect on vision under dynamic conditions. The current concerns of this group are twofold: (i) determining the incidence of otolithic insufficiency in an adult deaf population and (ii) quantifying the extent of visual disruption under varied controlled dynamic conditions. In preparation to evaluate otolithic function in a deaf population, a counterroll reliability study using adults with no hearing impairments was carried out (1). The second phase involves evaluating bilateral right and left eye counterroll in 100 deaf drivers who are members of a social club of the deaf.

The group is also completing the fabrication and testing of the dynamic experimental chair which will be used to evaluate visual disruption in persons selected from a population with otolithic insufficiency.

Occupant Protection

Investigator: Lawrence W. Schneider

Solving the problem of effective occupant protection for the severely disabled driver and passenger seated in a wheelchair requires that new and better devices and equipment be developed to deal with the various aspects of impact protection. As a result of sled tests conducted within the UM REC and elsewhere, some manufacturers have begun to redesign wheelchair securement mechanisms to be effective under realistic 30 mph impact forces. In addition to wheelchair securement, however, it is necessary to develop improved restraint systems for the person in the wheelchair. Some prototype design work for a wheelchair-mounted rear head restraint and four-point shoulder and lap belt restraint system has been conducted. The system attaches to and makes use of the strongest parts of the wheelchair frame at the junction of seat and seat-back tubing, and will be evaluated with sled impact tests in the near future.

Further design and evaluation of this and other devices will be carried out but a significant effort will also go into developing a brochure and/or guidelines booklet on occupant protection for wheelchair occupants in motor vehicles.

Driver-Vehicle Interface Development

Investigator: Simon Levine

As the severity of disability increases, more attention is focused on the basic automobile controls (i.e., acceleration, braking and steering). However, means for controlling auxiliary functions in a vehicle are also necessary. The primary goal of the interface laboratory is to develop standardized methods and equipment for interfacing drivers who have disabilities to the auxiliary controls of a vehicle.

A computer simulation system for secondary controls is being developed.

Information Dissemination and Service Delivery

Personnel:
David H. Harden,
Jolan Cossairt

A decision was made in the fall of 1981 to depart from biannual publication of the UM RECorder. Henceforth, its publication will follow significant achievements within the UM REC.

The assessment demonstration training education (ADTE) van continues to be a useful vehicle in the evaluation and training of severely disabled driver candidates.

Lawrence W. Schneider and Jolan Cossairt contributed a paper on Occupant Protection for Wheelchair Travelers to the Physical Disabilities Specialty Section Newsletter of the American Occupational Therapy Association. This article will reach about 4,000 occupational therapists.

The UM REC is continuing to contribute information to the ABLEDATA data base on equipment for disabled drivers.

A seminar on brain damage and driving is being planned to immediately precede the 1982 Annual Conference of the Association of Driver Educators for the Disabled. These meetings are planned for late summer in Ann Arbor.

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Rehabilitation Engineering Center Harvard University/Massachusetts Institute of Technology 300 Longwood Avenue, Boston, Massachusetts 02115

William Berenberg, M.D., Director

This is a report of the current activities and recent progress in the 14 projects conducted at this R.E.C. in the core areas of neuromuscular control using sensory feedback systems and communication.

Research is conducted at:

Children's Hospital Medical Center (C.H.M.C.)
300 Longwood Avenue
Boston, Massachusetts 02115

Brigham and Women's Hospital (B.W.H.)
52 Frances Street
Boston, Massachusetts 02115

Massachusetts Institute of Technology (M.I.T.)
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

Objective Quantitative Evaluation of Neuromotor Dysfunction

Sheldon R. Simon, M.D., C.H.M.C.

This project seeks to develop a system for the objective evaluation of human performance; it has several research areas.

Objective Interpretation of Gait Analysis Data — Evaluation of the feasibility and development of the techniques of an automated computerized gait interpretation system as reported in BPR 10-36 continues in collaboration with Professor Anthony Wong of the Sloan School of Management, M.I.T. Various methodologies were applied to the clinical gait kinematic data to determine if patient groupings of cerebral palsy could be established which would reflect a given patient's diagnosis and subdiagnosis. It was found that the five resulting clusters can be identified with different levels of severity of abnormal gait. Subsequent to cluster analysis (which is useful for groupings-identification) it was important to develop a classification scheme so that new patients can be assigned to one of the identified clusters. The recursive partitioning decision rule (Friedman 1977), used to construct a classification scheme based on the groupings obtained by the clustering method, demonstrated that the effects (on classification) of corrective measures such as surgery or assistive devices may well be more dependent on the classification scheme, which has been developed than upon the subjective evaluation of gait as determined by clinicians.

Upper Extremity Function in Children with Cerebral Palsy — Local orthopaedic surgeons who perform tendon transfers for cerebral palsied clients approached us to develop a system for evaluation of hands that would be on a par with our gait analysis system. Our first steps were to determine the feasibility of the adaptation of our system to the study of hand movements, and to collect basic information about the kinematics of normal reaching. Our system was modified to examine the kinematics of upper extremity motion (limb segment motion, shoulder, elbow, and wrist joint angular displacement and velocity changes, the trajectory of the reach, and the phasing of the grasp). Normal subjects were filmed as they reached to pick up objects from a table in front of them with their right hand. A pilot study indicates the feasibility of the project.

Mechanical Energy Analysis — Two systems for objectively examining mechanical energy during gait have been developed. One system uses four force

plates to measure all three components of the ground reaction forces exerted during a complete gait cycle. With this system it is possible to calculate the total change in mechanical energy over one gait cycle, assuming that there are no relative movements about the center of mass. The other system utilizes three-dimensional limb segment motion analysis to calculate the total body mechanical energy and individual segmental mechanical energies. A parameter called the Energy Correlation Coefficient (ECC) has been developed to indicate the energy transfers which occur between potential and kinetic energy for the total body and for individual segments and combinations of segments. The ECC is calculated by the following formula:

$$ECC = 0.5 - \frac{(\Delta PE)\,(\Delta KE)}{(\Delta PE^2 + \Delta KE^2)}$$

To determine the clinical usefulness of mechanical energy analysis, 15 patients and 5 normal subjects have had gait analyses done under a variety of walking conditions using the segmental method along with our more standard gait analysis. With this segmental energy analysis, the total mechanical work done per unit mass was found for each meter walked and for each second walked. To determine if this mechanical work could be related to metabolic work, plots were made of mechanical work per unit mass per unit time versus speed of walking. This relationship for patients and for normal subjects was compared to the metabolic energy curve, but a curve drawn through these points would be of the same shape as the metabolic energy curve.

The rate of mechanical work used by patients is almost always greater than the rate of mechanical work by normal subjects, but it also shows the same general relationship of increasing with velocity. This indicates that there may be a strong relationship between mechanical energy and metabolic energy in patients as well as normals.

Muscle Mechanics in Abnormal Gait—A complete system for the determination of muscle length, rate of change of length and joint moment has been developed. This consists of additional processing of the normally acquired three-dimensional kinematic force plate and myoelectric signal data. From the known kinematics of limb movement and the locations of the origins and insertions of muscles in the lower extremity, the muscle length at any time during the gait cycle is computed. This muscle length (which is a function of time) is then differentiated using finite impulse response digital filtering to yield the muscle rate of change of length. Joint moments are computed from the kinematics and force plate data using a three-dimensional analysis to yield the flexion-extension, abduction-adduction and internal-external moments at the hip, knee and ankle. The length and lengthening velocity and moment functions are then compared with the myoelectric signal (MES) to determine which features correlate with the onset of electrical activity.

The pattern of electrical activity in the pathological cases differed from the normal. In normals, the MES show a gradual rise in amplitude to a maximum followed by a relatively sharp drop in amplitude, whereas the pathological cases show just the opposite pattern.

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Comparative Gait Analysis and the Reconciliation of Research and Clinical Requirements

Robert W. Mann, Sc. D., M.I.T. and Neville Hogan, Ph. D., M.I.T.

The comparison of two separately evolved gait-analysis systems—one oriented towards clinical research and the other focussed on basic research—elucidates the reliability and efficiency of different data collection systems and the efficacy of findings derived therefrom.

A sensitivity analysis was conducted of the experimental and analytical components of optimization studies whose output is the prediction of individual muscle force level and temporal activity in normal level walking. The relative importance in the muscle prediction of the various elements of the experimental data—such as kinematic and force platform, the analytical estimation of dynamic intersegmental forces and moments and, in the optimization analyses, the choice of cost function and constraints applied to compensate for muscle redundancy—was evaluated, with particular attention to the correlation between individual muscle temporal pattern and the corresponding experimental EMG activity. The study conclusively demonstrates that kinematic data accuracy is the single most important and dominating factor in individual muscle activity outcome.

The optimization analyses, based on an evolving 36-muscle human leg model under development at M.I.T., indicated that individual muscle prediction was best at proximal and poorest at distal joints. Accordingly, an experimental effort has been mounted to generate an improved musculoskeletal model of the human ankle joint. A computer-controlled electrohydraulically activated, two-degree-of-freedom manipulation system for the human ankle has been designed and fabricated. Under computer control, the ankle joint can be manipulated dynamically over the full range of forces and movements within the physiological range, while the corresponding kinematic, force plate and electromyographic (surface and needle electrode) data are acquired, leading to an improved ankle-musculoskeletal model.

Studies on normal subjects in the ankle manipulator have just commenced. They will proceed under protocols involving computer-controlled force and position trajectories to establish the relationship between skeletal anatomy and myoelectric activity over the full range of the human ankle joint. Subsequently, studies will be im-

plemented on persons with disabilities in the ankle musculoskeletal system.

In a parallel investigation, a study was conducted to improve the detection and interpretation in gait analysis of the dynamic myoelectric signal. An MES transmission model was developed from basic electromagnetic theory and tissue electrical properties. The analytical predictions of the model were confirmed in experiments which provide insights into improved electrode placement and signal analysis of the dynamic MES in gait analysis.

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Portable Myofeedback Device

Carlo J. De Luca, Ph. D., C.H.M.C.

Over the past 5 years a revolutionary biofeedback device has been developed and tested. This device is particularly useful in busy clinical environments because it is small in size and has a dry electrode which may be instantaneously attached to the skin. During the past year the myofeedback device has been completely redesigned and is ready to be manufactured.

A manuscript, "A myofeedback instrument for clinical use", has been submitted for publication.

Muscle Fatigue

Carlo J. De Luca, Ph. D., C.H.M.C.
Rebecca Goodman-Rosenthal, M.S., C.H.M.C.

An automated device called the Muscle Fatigue Monitor which continuously, on-line and in real-time, tracks the median frequency of the EMG signal has been designed, constructed and tested. This device provides an objective measure for the physiological component of muscle fatigue, removing the psychological component which can commonly lead to serious erroneous subjective evaluations.

A series of studies are currently in progress to investigate the physiological mechanisms of localized fatigue in normal muscles. Studies have also been initiated to use the device and technique for evaluating the effect of exercise and the progression of muscular dystrophy.

Publications

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Objective Measurement of Spasticity

Mark Hallett, M.D., B.W.H., and Alfredo Berardelli, M.D., B.W.H.

The work to date has been summarized in three manuscripts which are now in press in the Journal of Neurology, Neurosurgery, and Psychiatry.

When a subject's foot was relaxed, stretch of triceps surae produced a single EMG component at short-latency which increased in magnitude with increasing velocity of stretch. This short-latency response (SLR) is not altered if the subject is asked to plantarflex or dorsiflex the ankle voluntarily when he feels the perturbation. It is significantly reduced by vibration of the Achilles tendon. If the triceps surae is stretched while the subject is voluntarily plantarflexing his ankle, the short-latency response is followed by one and sometimes two long-latency responses (LLRs). Like the SLR when the foot is relaxed, none of these responses are significantly altered by the subject's planned movement after feeling the perturbation. All of the responses are suppressed to a similar degree by vibration. The long-latency reflexes depend on long duration of stretching and relatively slow acceleration of stretch. The reflexes persist after anesthesia to the foot, suggesting that muscle afferents are responsible. The SLR when the foot is relaxed or exerting background force appears to be the monosynaptic, Ia mediated stretch reflex. The physiological properties of the LLRs are similar to those of the SLR, and it is conceivable that they represent, at least to a certain extent, response of the motor neuron pool to successive Ia bursts.

Electromyographic responses of triceps surae to dorsiflexion stretch were studied in 47 patients with a variety of lesions producing an upper motor neurone syndrome. The short-latency responses, both when the patient was at rest and when he was exerting a voluntary plantarflexion, were frequently enhanced in magnitude, and the rate of increase with acceleration was also enhanced. Long-latency responses were uncommon at rest. With background force, long-latency responses were present unless the short-latency response was very large. Long-latency responses could have a normal appearance, but in some patients they were either abnormally large in magnitude or abnormally configured with prolonged continuous activity.

The clinical assessment of the ankle jerk correlated with the magnitude of the short-latency response. The clinical assessment of tone correlated with the magnitude of the short-latency response, the magnitude of the long-latency response and the duration of the long-latency response. There appear to be multiple physiological mechanisms underlying the clinical phenomenon of spasticity.

Electromyographic responses of triceps surae and tibialis anterior to dor-

siflexion stretch were studied in 17 patients with Parkinson's disease. Most patients showed increased muscular activity when attempting to relax. A few patients showed an increase of short latency responses when relaxed and when exerting a voluntary plantarflexion prior to the stretch. Many patients showed long-latency responses when relaxed and all but one showed long-latency responses with voluntary contraction, and these responses were often larger in magnitude and longer in duration than those seen in normal subjects. Unlike the short-latency response, the long-latency response did not disappear with vibration applied to the Achilles tendon. The long-latency responses and continuous responses to slow ramp stretches were diminished at a latency similar to the beginning of long-latency reflexes when the stretching was quickly reversed. Dorsiflexion stretch also produced a frequent shortening reaction in tibialis anterior.

Of all the abnormal behavior exhibited by the Parkinsonian patients only the long-latency response magnitude and duration correlated with the clinical impression of increased tone. The mechanism of the long-latency response to stretch which is responsible for rigidity is not certain, but the present results are consistent with a group II mediated tonic response.

Demonstration of the clinical utility of phasic stretching by a correlation of results of stretching with gait study in patients with spastic cerebral palsy is now underway.

Suppression of Abnormal Involuntary Movements by Mechanical Loading

Michael J. Rosen, Ph. D., M.I.T.

The common theme of the projects which are included under this title is development and experimental evaluation of mechanical techniques for modifying disordered motor control. Compliant restraint, via orthoses and mechanically optimal device control interfaces, should permit selective reduction of abnormal movements while preserving expression of voluntary control.

Past work in this area has produced results of both practical and theoretical significance. In particular—

1. Data taken during tracking tasks under various loading conditions support a central oscillator model of pathological tremor;

2. Selective and clinically significant reduction of intention tremor by viscous loading has been observed;

3. A prototype damped joystick has been built and tested, with preliminary evidence showing dramatic improvement in figure-tracing ability;

4. The velocity sensitivity of spastic ankle stretch reflexes observed clinically was objectively verified, and a compliant orthosis simulator based on this data was designed.

Significant recent progress has been made in both upper and lower extremity work:

An experiment is underway to determine correlations between clinicians' subjective judgements of severity of tremor and objective instrumented measures. Neurologists experienced with movement-disorder patients are asked to view videotapes of tremor-affected limbs and more global views of clinical examination procedures. Their ratings of severity and estimates of tremor frequency will be tested for statistical correlation to processed goniometric data. The goal is development of a clinical scoring instrument.

Normal tremor studies have been in progress to improve understanding of tremor generally. Data shows decreasing tremor frequency and amplitude as mass is added to the limb. (This is in contrast to data of Stiles (1976) in which mass and gravitational torque were confounded.) Simulation of an underdamped third-order mechanical model shows *increased* resonant peaks with increased mass. This apparent inconsistency has been explained via Watanabe's model which includes interaction of system biomechanics with short-latency and long-latency reflex loops. (Personal communication; Dr. Akira Watanabe of the Institute of Medical Electronics, Faculty of Medicine, University of Tokyo was a Visiting Professor in the Department of Mechanical Engineering, M.I.T., from August 1980 through December, 1981.) This model shows movement of tremor frequency away from the resonant frequency as mass is added, and this is consistent with our data to date.

Work on the compliant ankle orthosis simulator has advanced; a working computer-interactive system is in frequent experimental use. Software has been prepared which allows implementation of viscous and velocity-squared damping with a range of damping constants and various timing patterns with respect to the gait cycle.

Tests to date with a spastic cerebral palsied subject have produced several promising results. First, the weight of the simulator, ~ 3 lbs, has little effect, in itself, on the gait of this juvenile subject. Second, the subject adjusts quickly to the changed "feel" of the orthosis as various loading schemes are tried. Most important, certain trials with particular loading schemes show a complete absence of the subject's characteristic premature and exaggerated plantar flexion.

In upper-extremity work, experiments in tracking control of isometric force will continue. The goal is to test the hypothetical advantage of a rigid interface and tremor-attenuating signal processing for proportional input to environmental control and communication devices. Design and testing of a damped planar arm restraint and a head restraint system are also underway.

In the spasticity research, further data collection from spastic subjects is planned. Data will be interpreted for clinical significance and to test the original hypothesis that limitation of dorsiflexion rate will prevent excitation of the stretch reflexes which generate equinus and back-kneeing. Ultimately, a practical, compliant orthosis for ADL evaluation will be built, incorporating the conclusions from the simulator experiments.

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Neurophysiological Feedback from Extremities

Neville Hogan, Ph. D., M.I.T.

The purpose of this project is to improve the utility of myoelectric activity as a practical biological control signal for interfacing a human operator with assistive devices such as prostheses, orthoses, environmental control units, powered wheelchairs, computer terminals, etc., and to determine to what extent a high-fidelity command pathway will reduce the need for artificial external sensory feedback.

Improved myoelectric control requires a myoprocessor which yields a timely high-fidelity signal which accurately and reliably estimates physiological muscle activity. A new processor has been developed which is almost 10 times more accurate than conventional myoprocessors without compromising speed of response.

To determine the motor intent of the human operator, it is essential to interpret the myoelectric activity correctly. Fundamental neurophysiological research has shown that the central nervous system controls limb trajectory and position by simultaneously specifying the equilibrium condition for the limb and the mechanical stiffness or impedance about the joint. Independent control of equilibrium position and impedance is achieved by co-activation of antagonist muscles.

A digital computer implementation of the improved myoprocessor has demonstrated the ability to estimate muscle force under isometric conditions with plus-or-minus 2 percent RMS error at frequencies up to two cycles per second. The earlier lengthy calibration procedure has now been made completely automatic, to the point where tests show that the system calibrates itself successfully and produces real-time estimates of muscle activity with the predicted high fidelity. Hardware implementation is underway on a controller which interprets the activity of biceps and triceps as specifying both a target equilibrium position for the elbow joint and the impedance about the joint. Concurrent neurophysiological research has shown that this is the mechanism through which monkeys retain their ability to point with the upper limb, even after deprivation of sensory information through dorsal-root deafferentation and occlusion of visual feedback. We are investigating the extent to which the low stiffness about the joint, coupled with the inertial effects of the driven limb, will yield a mechanical filtering effect which will further improve the fidelity of the command pathway. This latter study avails itself of the single model of a new high-performance elbow prosthesis (developed under the N.S.F. Program of Technology and Science to Aid the Physically Handicapped).

The new myoprocessor, the multiple-muscle controller, and the high-performance prosthesis will be fitted to amputee subjects, and studies will be conducted to compare the new control approach and low-stiffness prosthesis with standard, velocity-controlled devices such as the "Boston Elbow" currently produced by Liberty Mutual Insurance Co. Research Center, (at Hopkinton, Mass.), whose productive collaboration with our project continues. This phase of the project will involve an in-depth psychophysical evaluation of the amputee user's need for external sensory feedback when using new control concept. We hope, of course, to demonstrate the similarities between the pointing competence of the deafferented monkeys and our amputee subjects who suffer proprioceptive loss from the ablated joint.

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Postoperative Gait Training System

Woodie Flowers, Ph. D., M.I.T.

The purpose of this project is to develop instrumentation to augment postoperative gait training for above-knee amputees. A prototype system was developed and used in training seven hospital inpatients. An acoustic biofeedback signal was used as a weightbearing and knee-lock threshold indicator. Experience with the prototype system indicated that substantial training program improvements could result from use of similar instrumentation.

A new, microcomputer-based, hand-held training system is nearing completion. The new system, designed and built by graduate student Kevin Paul Tyra, uses the techniques developed earlier, but also allows other display and feedback modes to be tested. Its operation is very straightforward and should be used easily in a gait-training environment. The next step in the project is to evaluate the new system in a hospital.

UNICOM: Non-Vocal Communication System

Derek Rowell, Ph. D., M.I.T. and George Dalrymple, M.S., M.I.T.

The UNICOM (Universal Communicator) is a microprocessor-based system that allows a wide variety of communication modes and functions. Seventeen UNICOMS have been constructed and placed in service in schools, hospitals and homes.

The work of monitoring and evaluation of units in the field continues. New user interfaces and extensions to the software, to allow the unit to act as a computer terminal and an environmental controller, have been developed.

The UNICOM has been successfully evaluated under a wide range of field conditions, and the concept and power of the software have been demonstrated. A manufacturer is sought to commercially develop the concepts generated in this project.

Computer-Assisted Prediction of Non-Vocal Communication Rate

Michael J. Rosen, Ph. D., M.I.T.

In the context of clinical prescription of nonvocal communication devices for the motor handicapped, achieving the maximum rate of communication is a major objective criterion of success. Since rate is a property of the user-machine system, the only present means of determining rate is by literal device-by-device testing with a client. This project is intended to develop a more practical alternative — a technique in which communication rate will be predicted by a computer program, based on assessment data from abstract target-acquisition movements.

An analytical framework has been developed to allow determination of communication rate from user and device variables, and to facilitate comparison of superficially diverse systems. A clinical prescription procedure, incorporating the rate prediction algorithm, has been outlined in collaboration with Dr. Cheryl Goodenough-Trepagnier of Tufts-New England Medical Center. This procedure should provide a systematic objective means of matching devices to users for optimal performance and satisfaction.

A structure for the rate-prediction algorithm and assessment procedure has been developed and is outlined here. It provides a means of combining information which abstractly characterizes an individual's movement with specifications of particular device characteristics, leading to calculation of expected time-per-word. (It is assumed that device information will be available in standard format disc files.)

The first major routine in the algorithm controls Testing and Response Storage (TRS). Subjects are asked to touch (e.g. with finger, hand, headstick) illuminated targets as they appear on a planar array. The time of target acquisition is transduced by a touch-sensitive surface which outputs coordinate information to the computer. Movement times for the tested values of initial and final coordinates are stored in a memory array.

In the next phase, Interface Use Prediction (IUP), the interface geometries of specific candidate systems are read in from disc files. Based on the time-versus-position information stored in TRS, key-to-key times are predicted for all movements required in the use of a device.

The final routine undertakes Communication Rate Calculation (CRC). Additional data on each device are read in from its file, specifically the frequency of occurrence in representative text of each of its language units, and the code which relates key sequences to units. From these and the predicted interface act times from IUP, average time per word is derived.

Implementation of a working computer program with the above structure is in progress, as is design of the target presentation and movement transduction hardware. Detailed trajectory records of target acquisition movements will be taken by TRACK, the M.I.T. Biomechanics and Human Rehabilitation Laboratory's computer-based system for real-time acquisition of kinematic data. These records will be used for off-line analysis of speed/accuracy tradeoffs and other aspects of impaired voluntary movement. Experimental verification of the algorithm's predictions by comparison with actual communication rates is planned.

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Clinical Engineering and Rehabilitation

Philip A. Drinker, Ph. D., B.W.H.

In earlier phases of the study we participated in the development and clinical evaluation of the UNICOM. An important aspect of that work was the development of interface strategies, including hardware, allowing use of the UNICOM by multiply handicapped individuals.

During the past year we have focused increasingly on the needs of individual patients in a hospital who require special adaptive or rehabilitative devices that are not available in the existing market. These efforts range from communication, to wheelchair modifications (especially controls for battery operated chairs), to custom ostomy applicances for patients who have a malformed stoma that cannot be revised.

Of particular interest this past year has been the striking success of our transparent direct-selection board, Eye-Link, for use by paralyzed nonvocal individuals. Since the time of our earlier report (BPR, September, 1981) we have used it with four additional patients: one with Guillain-Barre, three with ALS. Because of its simplicity, it is far more acceptable to both patients and nursing staff than other boards tried, and it makes a very practical first approach to communication in the acute care setting.

Refreshable Braille TSPS

Derek Rowell, Ph. D., M.I.T. and George F. Dalrymple, M.S., M.I.T.

Two TSPS telephone operators consoles were designed and installed at Southwestern Bell Telephone Company in Little Rock, Arkansas in 1977. Two blind operators have used these systems successfully since that time. During the current report period, the project provided maintenance and support for the two prototype systems and provided modifications as the company upgraded the TSPS system.

R.E.C. involvement in this project has been successfully completed. The replacement of the two R.E.C. developed units with the commercially developed system is anticipated.

Ultrasonic Mobility Aids for the Blind

Robert W. Mann, Sc. D., M.I.T. and Derek Rowell, Ph. D., M.I.T.

Independently, a new employee at Polaroid adapted the Polaroid ultrasonic system to a long cane, an M.I.T. student conducted a feasibility study on adapting the Polaroid sensor to the

M.I.T. Cable Cane, and the American Foundation for the Blind undertook the development of a microprocessor-based Computerized Travel Aid (CTA) which provides a variety of visual, auditory code, and spoken speech outputs from the Polaroid sensor.

These Polaroid-sensor-based efforts have coalesced into a cooperative project managed by M. M. Uslan, National Coordinator of Mobility and Orientation of the American Foundation for the Blind, with the active participation of W. R. Smith, of the Sensory Institute of Boston College, Dr. C. H. Biber, of the Polaroid Corp., and Professors R. W. Mann and D. Rowell at M.I.T. The project leader is an M.I.T. undergraduate, K. Schriebman, who together with several other students, in the context of the M.I.T. Undergraduate Research Opportunities Program and Bachelor theses, are advancing the research.

Field tests, using an early version of the CTA with a single transducer, demonstrated the desirability of achieving both a broad beam with side lobes of shorter range and a pencil beam of extended range — together with the ability to switch from beam to beam. Two parallel approaches to achieve this flexibility are underway.

At A.F.B., the use of two complete Polaroid send-receive transducers is being explored, while at M.I.T. a monopulse technique which subdivides a single transducer into four segments is being studied. In addition to these efforts to reshape the ultrasound beams, psychoacoustic experiments are optimizing the tonal outputs of the auditory display, and transducer mounts are being designed and fabricated to provide the blind user with the flexible options of cane mounting or chest mounting or hand manipulation of the travel aid transducer(s).

Field testing of the alternate approaches is planned for the spring of 1982 and will in part be documented in Mr. Schriebman's Bachelor's thesis.

Publications

Computerized travel aid development program. Progress Report II, American Foundation for the Blind, Feb. 16, 1982.

Cerebrospinal Fluid Shunt/ for Normal Hydrocephalus

Robert W. Mann, Sc. D., M.I.T., Derek Rowell, Ph. D., M.I.T., and Keasley Welch, M.D., C.H.M.C.

Ventricular dilation and brain distention in hydrocephalus are currently managed by the surgical insertion of a pressure-sensitive relief valve which ports cerebrospinal fluid to the right atrium or the peritoneal cavity.

This project is exploring the feasibility of a servocontrolled cerebrospinal fluid shunt designed to maintain the normal relationship between ventricular pressure and subdural pressure, thereby mitigating normal pressure hydrocephalus.

This project is conducted by doctoral candidate Carlos Hakim, whose interest in this area has been motivated by the clinical practice and research of his neurosurgeon father. Prior hydrocephalic research at the Harvard-M.I.T. R.E.C. has established collaboration between M.I.T. and the C.H.M.C. Neurosurgical Service, making the R.E.C. an ideal environment in which to further this research.

The servo-controlled shunt valve, which uses subdural pressure as the input to control ventricular-to-venous flow, has undergone several design iterations and has been fabricated by Mr. Hakim at the Cordis Corp., Miami, Florida. Subdural pressure will be measured by a commercially available transducer. Arrangements have been made at C.H.M.C. for research with the system on normal and hydrocephalic dogs.

Extensive in vitro calibrations of the servo valve are planned. These will be followed by implantation in normal dogs, to determine how the subdural pressure changes with changes in body orientation from vertical to horizontal. Subsequently, experiments will be conducted on hydrocephalic dogs. In Bogota, Colombia, during otherwise necessary surgery on humans, the subdural pressure as a function of body attitude will be determined. On the basis of these animal and human experiments, the servo-shunt design will be refined.

Rehabilitation Engineering Center Rehabilitation Institute Ljubljana 61000 Ljubljana, Linhartova 51 Yugoslavia

Stanislav Plevnik, M. Sc., Acting Project Director, Prof. Alojz Kralj, D. Sc. Project Director, Ruza Acimovic-Janezic, M.D., Co-director.

This report covers the period from April 1, 1980 to March 31, 1981.

The core area of the Ljubljana REC project is functional electrical stimulation (FES) of human extremities and urogenital mechanisms. In 1980 and 1981 the activities were carried on by seven task groups on which we are reporting.

Multichannel FES of Lower Extremities

U. Stanic, D.Sc., R. Acimovic-Janezic, M.D., M. Malezic, Dipl. Eng., J. Krajnik, Dipl. Eng., M. Kljajic, D. Sc., P. Strojnik, M. Sc., M. Stopar, Eng., N. Gros, P.T.

The purpose is to develop the methodology of multichannel electrical stimulation for therapy and orthotic use in hemiparetic and paraparetic patients for correction of abnormal locomotion.

The research work performed so far has shown that the application of surface stimulation to the main leg muscle groups can significantly normalize paretic gait.

The study of reorganization of motor activity due to multichannel stimulation in posture and gait was started. Preliminary results indicated positive short-term and long-term effects on the activities of stimulated muscles. Also, the contributions of different numbers of channels used in surface stimulation were studied on a group of

10 hemiplegic patients, with the aim to construct a two-channel orthotic stimulator for home use.

Clinical evaluation of the one-channel implant peroneal stimulator has been carried on. Seven implantations have been performed so far. The results are very promising. Also, the biocompatibility study including the tissue reaction studies of biocompatible silicone rubbers dissolved in locally available solvents (xylene, touluene, benzine) are performed. Also, several shapes of Hysol epoxy resin specimens are tested in white rats.

A microprocessor (Cosmac CDP 1802) controlled 6-channel surface stimulator was designed and successfully tested. Further implementations have been performed in the software package for processing gait measurements.

For the immediate future the following tasks are planned: the use of percutaneous electrodes for multichannel implant electrode sites in animals; angle-controlled peroneal stimulator; adaptation of EMG measuring system; and clinical evaluation of microcomputer-based 6-channel stimulator.

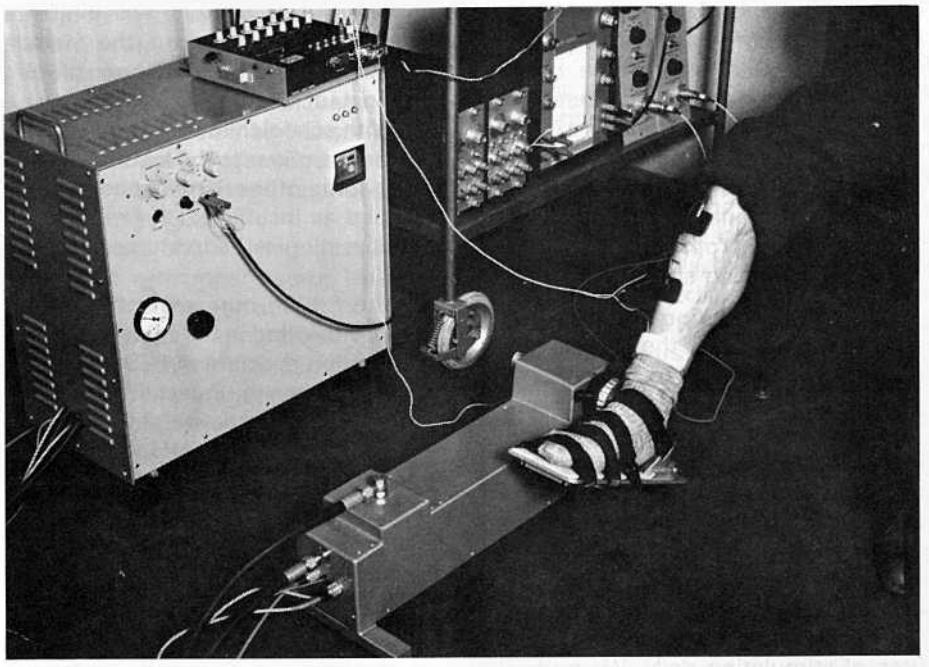

FIGURE 2.
Electrohydraulic servosystem for physical therapy of ankle joint and the measurement of resistive torque.

FES of Spinal-Cord-Injured Patients

A. Kralj, D. Sc., R. Turk, M.D., and T. Bajd, D. Sc.

The purpose is to electrically stimulate the paralyzed muscles in paraplegic and quadriplegic patients to make it possible for them to perform functional activities such as: standing up, standing, walking, and grasping and holding objects.

In previous research on muscle-strengthening with FES, prolonged standing, and opening and closing of the hand, were achieved.

Standing up of complete paraplegic patients by stimulation of both knee extensor muscles and by the help of arm support was achieved. Standing was improved by introducing biofeedback training. Two-channel stimulators for standing were given to nine patients for home use. Flexion synergistic response was studied with the aim to perform swinging of the paralyzed leg during walking. A four-channel stimulator for gait synthesis in paraplegic patients was developed. It was given to a T-5 complete paraplegic patient who is walking for 3 hours each day with the help of FES and a walker (Fig. 1).

Further study of neurophysiological phenomena and biomechanical properties of FES movements of the spinal-cord-injured patients will be performed in the immediate future.

FIGURE 1.
Complete paraplegic patient walking with the help of four-channel stimulator and walker.

Electrotherapeutic Methods for Extremities

L. Vodovnik, D. Sc., Stanislav Rebersek, M. Sc., and V. Valencic, D. Sc.

The purpose of this investigation is to improve our understanding of physiological mechanisms of electrotherapy and develop new methods of treatment with electrical stimulation.

The previous research on denervated muscles shows that, at a minimum, functional movements can be produced by means of electrical excitation.

Electrical therapy of spastic joint — For the measurement of spasticity represented by the resistive joint torque, an electrohydraulic servosystem is used enabling precise positioning and adequate frequency capabilities. A typical experimental set-up is shown in Fig. 2. The therapeutical electrical stimulation of soleus and tibialis muscles is alternately switched every half of movement period. Five patients

were treated and in two cases significant decrease of resistive torque was observed. In the other three cases, practically no changes were detected.

Plans for the immediate future in this area are differentiation of therapeutic effects for various regimens of stimulation (agonist, antagonist, combined) and study of neurophysiological phenomena underlying spasticity.

Electrical stimulation of denervated muscle —The goal of the experiments and investigations on the denervated muscles was to obtain a functional movement by means of electrical stimulation. The experiment was performed in five healthy subjects and in a set of eight patients with complete denervation of the tibialis anterior.

Positive effects were noticed during electrical stimulation therapy during four weeks of training with 2x30 minutes of stimulation daily. We noticed significant improvement of the ankle response. The study shows some possibilities of optimization of electrotherapy and defines the parameters of functional electrical stimulation to these patients.

Verification of results obtained until now will be attempted in the near future on a larger number of patients.

Neurophysiological Investigations of Improvements in the Pathological Motor Activity Due to FES

F. Gracanin, D. Sc., M.D., R. Blumauer, M.D., V. Vuckovic-Zeljic, M.D., S. Ugrinovski, Dipl. Eng., T. Zrimec, M. Sc., and G. Vrabic, P.T.

The purpose is accelerating the development of insufficiently developed motor functions of the locomotor system and restoration of the impaired motor function of the locomotor system.

During the previous years we developed the FES method and submitted the indications for the application thereof to patients with hemiplegia, paraparesis, some cases of multiple sclerosis, cerebral palsy children, and children with idiopathic sclerosis. In addition to the use of FES, audiovisual EMG biofeedback therapy in the restoration of motor function (particularly the hand) was introduced.

During the past year, progress has been made in the following fields:

1. We found that, with healthy persons as well as persons with an impaired upper motoneuron, the motor response at FES of n. peroneus was not constant.

2. With schoolchildren we observed different reactions to the loading of the spine; some of these reactions can be regarded as insufficient for maintaining physiological curvatures of the spine.

In the future, our research will be primarily directed to the solution of the optimization problem in FES irrespective of whether the question is of the acceleration of the development of undeveloped motor functions or else substitution in cases of absolute absence.

FES of Urogenital Mechanisms — Design of Orthotic Aids and Special Measuring Systems

P. Suhel, D. Sc., B. Kralj, D. Sc., M.D., E. Roskar, M. Sc., and M. Pajntar, D. Sc., M.D.

With a view to getting a clinically reliable diagnostic algorithm for a microcomputer-controlled urodynamic system, a study has been initiated of vesicourethral dysfunctions during extreme stress (i.e. the full bladder and an increased intraabdominal pressure developed during coughing). Aside from measuring the interrelationship of intravesical and intraurethral pressure, a simultaneous recording of surface EMG of the periurethral striated sphincter with the aid of urethral ring electrodes has been also included. A laboratory EMG amplifier was designed for the precise amplification of the detected EMG activity. The preliminary results in 5 females with urge incontinence and in 15 females with stress incontinence indicated the significance of measuring the timely activation of the urethral sphincter at the sudden increase of intra-abdominal pressure, particularly in patients with stress incontinence. The method of detecting surface urethral sphincter EMG was proved to be convenient, and surface EMG findings have always coincided when control needle EMG recordings have been done.

Fundamental findings have been achieved concerning the usefulness of hypnotherapy in treating urinary incontinence in females. In 5 females, i.e. in 2 with urge incontinence and in 3 with mixed stress urge incontinence, hypnotherapy was administered after all other therapeutic methods had either failed or had been refused by the patients. The effect of hypnotic therapy and/or suggestion was noticed in all 5 cases. Both patients with urge incontinence were completely cured, while in the remaining 3 cases of mixed incontinence, improvement was noticed.

The Vagicon-X AMFES and the Vagicon-AMFES stimulator, developed for home treatment in cases of relapse of urge incontinence, are in the clinical evaluation stage and this evaluation will continue. The possibility of evaluating EMG responses during voluntary, reflex, and electrically evoked contractions of the urethral sphincter will be investigated.

FES of Urogenital Mechanisms Physiology, Techniques of Stimulation, and Methods of Urodynamic Evaluation

S. Plevnik, M.Sc., J. Janez, M.D., S. Rakovec, M.D., D.Sc., P. Vrtacnik, Dipl. Ing., L. Ravnik, M.D.

The purpose of this task is to develop and evaluate new methods of electrical stimulation for urinary incontinence, develop and evaluate new urodynamic and other diagnostic methods, and evaluate physiological mechanisms involved in electrically stimulated lower urinary pathways.

The method of short-term maximal electrical stimulation for urinary incontinence was improved by using self-stimulation techniques, thus reducing discomfort during stimulation. The possibility of measuring the urethral wall softness was also studied with the aim of assessing a so far unmeasurable diagnostic parameter which can be a primary cause of urinary incontinence in many patients with urinary incontinence.

Short-term maximal electrical stimulation (MES) of the pelvic floor muscles, applied one or several times, proved to be a useful method in treating urinary retention. Six patients with spinal cord lesions from C5 to T4 having urinary retention were treated with MES. After MES, five patients are now

able to provoke reflex micturition for periods of from 8 to 14 months. Urodynamic examinations show that, in these cases, MES produced prolonged inhibition of the previously hyperactive bladder as well as prolonged inhibition of the previously hyperactive urinary closing muscles.

The method called electric fluid bridge test for evaluation of urethral incompetence was developed. The entry of the urine in the proximal urethra during stress was detected as the change in the impedance across the measuring electrodes since there is a significant difference between the impedance of the inner urethral walls and that of the urine or saline which is previously introduced into the bladder.

The method for measuring internal urethral softness (IUS), noted above, was improved in order to make it clinically accessible, and preliminary testing was done.

Clinical evaluation of the IUS method and electric fluid bridge test will be performed.

FES of Urogenital Mechanisms—Studies of Urodynamics and Evaluation of Orthotic Aids

L. Ravnik, M.D., D.Sc., J. Janez, M.D., S. Plevnik, M.Sc., S. Rakovec, M.D., P. Vrtacnik, Dipl. Eng., and G. Homan, M.D.

The purpose of this task is to evaluate orthotic and therapeutic efficiency of different methods of electrical stimulation for correction of urinary incontinence by means of urodynamic and other diagnostic methods. Previous efforts have included urodynamic and clinical evaluation of short-term maximal electrical stimulation (MES) for urinary incontinence.

Progress has been made in the understanding of the basic mechanism of action of MES on urinary bladder and distal urethral sphincter.

Pharmacologic studies were performed on stimulated and unstimulated animals. MES produced increased beta adrenergic activity in detrusor muscle, while the activity for cholinergic receptors decreased. From the method used it is not possible to conclude about the nature of these changes (increased number of receptors, altered affinity) but it is possible to explain to a certain extent bladder inhibition and long-term effects of electrical stimulation.

Histochemical studies of distal urethral sphincters which were performed in stimulated and unstimulated animals are suggesting that MES could produce only neuronal but not muscular changes.

The effects of MES were studied in 15 patients with upper-neuron lesions, using combined urodynamic and roentgenologic investigations. Vesico-ureteric reflux was present in 2 of these patients, while upper urinary tract dilation with poor renal function was observed. After MES was used, urinary incontinence disappeared or was diminished; vesico-ureteric reflux disappeared in both patients and upper-urinary-tract dilation was diminished. These examples showed us that MES may be indicated even in patients with vesico-ureteric reflux and upper-urinary-tract dilation due to neurogenic bladder dysfunctions.

Plans for the immediate future: — Preliminary results in patients with lower-motor-neuron lesion (central and peripheral) showed that, using MES, a good clinical effect could be achieved after several repeated stimulations. In order to determine what kind of changes may occur after MES in this group of patients, combined urodynamic, neurophysiological, and urological investigations will be done before and after several stimulations.

The opportunity presents itself for listing the addresses of the individual constituent projects of the Rehabilitation Institute Ljubljana REC. They are presented here by report title and mailing address, in the same order that they appear in this issue's REC progess report. As always, the REC address and names of directors appears at the heading of the REC report, and names of investigators appear with the headings of the individual project progress reports.

Multichannel FES of Lower Extremities

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FES of Spinal Cord Injured Patients

University "E. Kardelj"
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Electrotherapeutic Methods for Extremities

Faculty of Electrical Engineering
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Neurophysiological Investigations of Improvements in Pathological Motor Activity, due to FES

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FES of Urogenital Mechanisms: Physiology, Techniques of Stimulation, and Methods of Urodynamic Evaluation

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FES of Urogenital Mechanisms: Studies of Urodynamics and Evaluation of Orthotic Aids

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